UNIVERSITY OF ALBERTA

HYDROGEOLOGY OF TRI-CREEK BASIN, ALBERTA

by

© D. V. CURRIE, B.Sc., B.Ed.

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF GEOLOGY

EDMONTON, ALBERTA

SPRING, 1969

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled "Hydrogeology of Tri-Creek Basin, Alberta, submitted by D. V. Currie, B.Sc., B.Ed., in partial fulfilment of the requirements for the degree of Master of Science.

ABSTRACT

The investigation was done to establish the physical relationships between geology and groundwater regime in a structurally disturbed Foothills environment.

Rocks of the Upper Cretaceous Alberta Group and Brazeau Formation underlie the basin. Dark grey shales and rusty-weathering, hard, sandstones of the Alberta Group are exposed along the Brazeau thrust. The green-grey sandstones and shales of the Brazeau Formation are folded and faulted.

Three glacial tills are present: a local till which contains local bedrock material, the Marlboro till containing quartzite pebbles, and the McLeod Valley limy till of which almost 50 per cent of the pebbles are carbonates.

The northern quarter of the basin is covered with easily eroded glacio-lacustrine silt. Ice-contact stratified drift deposits are located in the valleys.

The basin has a local relief of 1,400 feet. The three sub-basins are of the fourth order and have drainage densities ranging from 3.3 to 4.7 miles per square mile. The bifurcation ratios range from 3.0 to 5.6.

A plant association of lodgepole pine, broom grass, and bearberry is indicative of natural groundwater recharge conditions. Natural groundwater discharge is indicated by a spruce-fir association with haircap and sphagnum moss.

Individual groundwater discharge features include: springs of the rock debris type, which issue from the ground at a change in topographic slope and have boulders in the channel leading away from the spring; springs of the soaphole type, which issue from a vertical cylindrical hole in local areas of flat topography; and rough-surfaced groundwater seepage areas, termed hummocky ground.

The vegetative zonation around individual groundwater discharge

features is sedge to swamp birch.

Hypothetical groundwater flow patterns demonstrate groundwater flow into the basin at the divide and out of the basin at the McLeod River. Geological nonhomogeneities cause concentration of upward flow at fault zones.

Four piezometer nests and four water table wells have been established in the basin.

Transmissibility values of 136 and 176 igpd/ft for the Brazeau Formation and 70 igpd/ft for the Wapiabi Formation were derived by bail tests. These values are comparable to those assumed for the hypothetical groundwater flow pattern.

ACKNOWLEDGEMENTS

Sincere acknowledgement is due Dr. A. J. Broscoe, thesis supervisor, who visited the field area, reviewed the photogeology and manuscript, and offered helpful suggestions.

The Research Council of Alberta, Groundwater Division, has provided the financial and technical support for the thesis. Mr. D. R. Stevenson, hydrogeologist with the Division, engendered the writer's initial interest in hydrogeology. Both he, Dr. J. Toth, head of the Division, and Mr. D. H. Lennox, former head, provided encouragement.

Dr. J. A. Westgate visited the Tri-Creek basin and did much to aid in the interpretation of surficial geology.

Mr. A. Peter, Alberta Forest Service, and his staff at the Robb ranger station provided, often under arduous conditions, data basic to all fields of study. Without this co-operation Tri-Creek Experimental Research Basin could not function.

Mr. H. Weiss, Groundwater Division of the Research Council of Alberta, is responsible for the draughtmanship displayed in this report. His cheerful co-operation was greatly appreciated.

Mr. J. Dumanski, and his staff at the Research Council of Alberta Soil Survey Laboratory, provided the calcium carbonate determinations of surficial materials.

Thanks are due the British American Oil Co. and the Sun Oil Co. for providing seismic shot-hole information.

A very sincere expression of gratitude is extended Miss D. Cunliffe who typed the manuscript.

TABLE OF CONTENTS

Page

Page

LIST OF FIGURES

LIST OF TABLES

LIST OF PLATES

Page

LIST OF MAPS

INTRODUCTION

General Statement

The Tri-Creek basin investigation is designated International Hydrologic Decade Experimental Research Basin Number 1 W.B.-E.B.-13. One of the objectives of the International Hydrologic Decade is to accelerate the study of water resources and the regimen of waters with a view to their rational management in the interests of mankind.

This thesis is a progress report on initial investigations toward a more comprehensive study of the region.

Location

The name Tri-Creek basin is used to designate the area drained by three northward flowing tributaries of the McLeod River. They are Wampus, Deerlick, and Eunice Creeks.

Tri-Creek basin is situated at 53°09' north latitude and 117°15' west longitude (Fig. 1). The basin has an area of 23 square miles, and includes parts of townships 47 and 48, ranges 22 and 23, west of the fifth meridian, Alberta.

The basin is located within the disturbed Foothills belt of west central Alberta, approximately 180 miles west-southwest of Edmonton, and five miles north of the hamlet of Cadomin (Fig. 2).

Topographic elevations range from 5,527 feet to 4,133 feet over an averaged distance of 5.3 miles. This results in an average gradient of the main stream channels of 265 ft/mile.

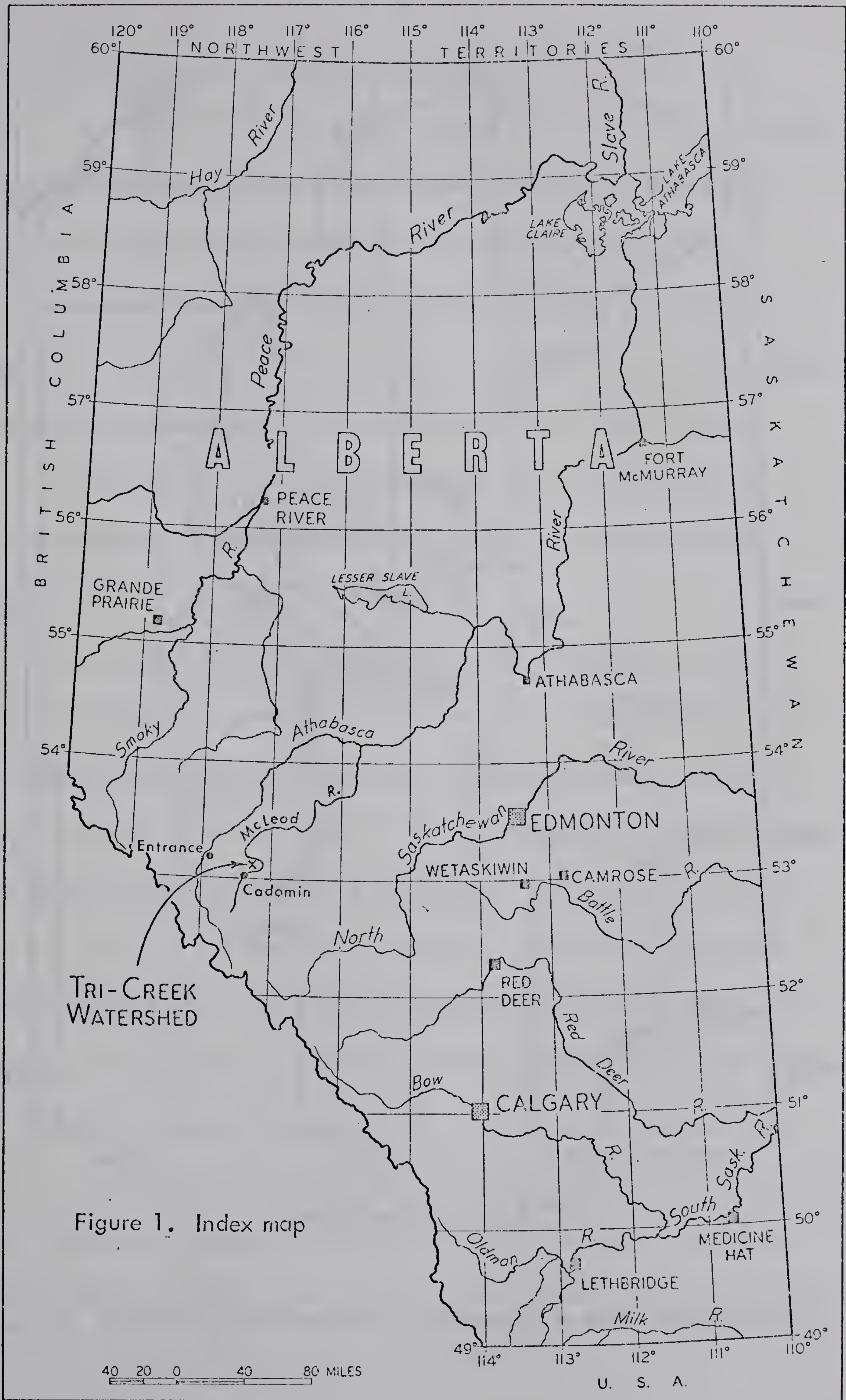


Figure 1. Index map

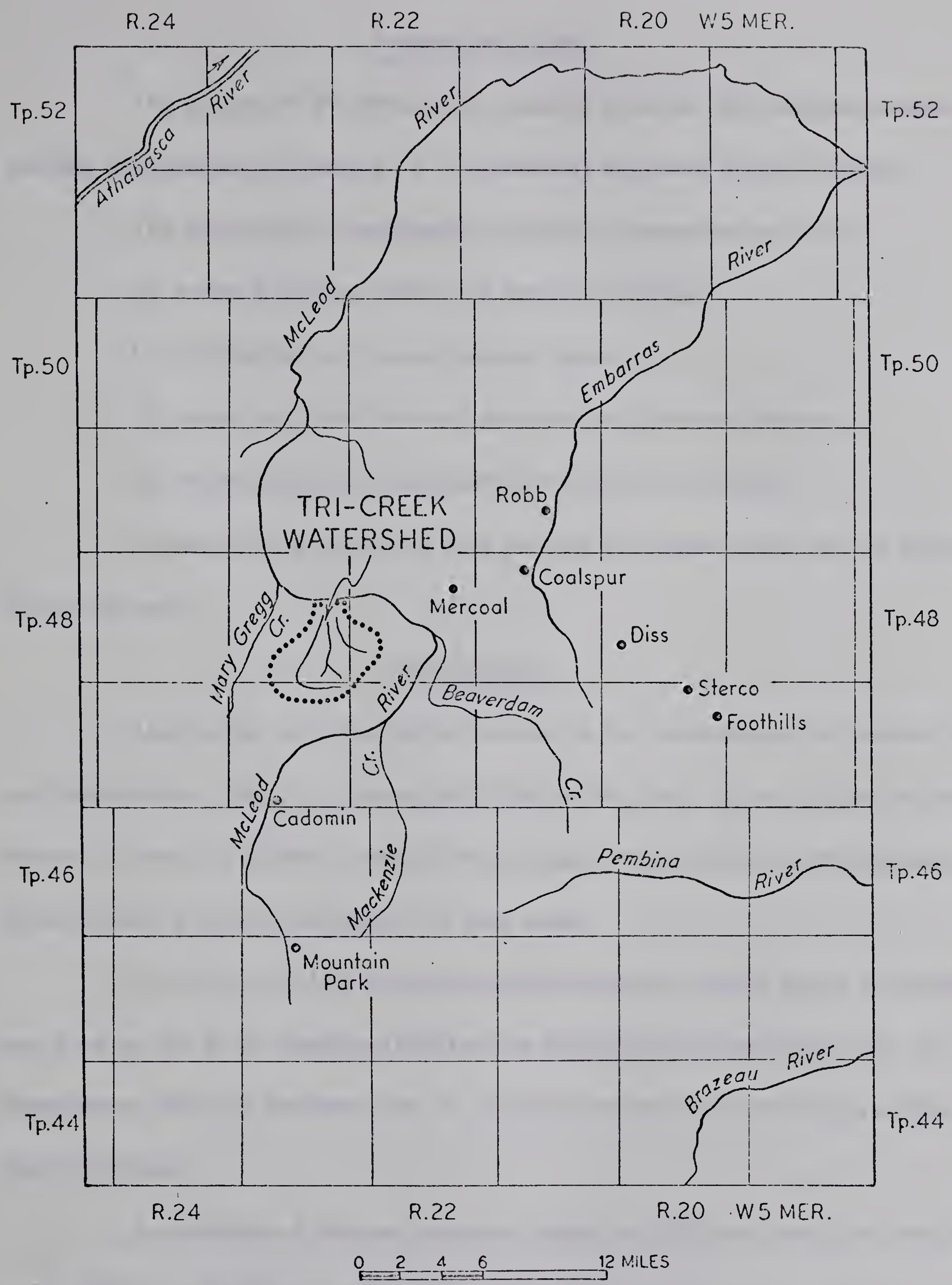


Figure 2. Location of Tri-Creek basin with respect to major drainage systems

Purpose and Scope

The purpose of this thesis is to establish physical relationships between geology and groundwater regime in a moderately disturbed Foothills region.

The scope of the investigation includes a determination of the:

a) bedrock geology within the basin boundaries;

b) distribution and type of glacial deposits;

c) nature and distribution of groundwater discharge features;

d) transmissibility of sediments by the bail test method.

Hypothetical groundwater flow patterns have been drawn for the Wampus Creek sub-basin.

Previous Work

Most of the early geological interest in the general area was related to coal exploration. Dr. R. L. Rutherford (1924) of the then, Scientific and Industrial Research Council of Alberta, mapped the geology between McLeod and Athabasca Rivers primarily to outline prospective coal areas.

The only published detailed geological map to include a part of the basin was done by Dr. B. R. MacKay (1929) of the Geological Survey of Canada. Information on this map indicates that Dr. MacKay traversed a short distance along Deerlick Creek.

Exploitation of the coal resources began in 1912, and continued until the early 1950's. At this time, an increasing demand for petroleum resources brought seismic exploration to the Mercoal-Cadomin area. These endeavors culminated in the drilling of two wildcat wells, in what is now Tri-Creek basin:

1) B.A. et al. Kaydee 14-12-48-23-W5M. This well was begun February 23, 1959 and abandoned September 13, 1959, at a total depth of 10,031 feet.

2) B.A. et al. Kaydee 5-7-48-22-W5M. This well was begun January 16, 1960, and abandoned at a total depth of 14,058 feet on October 4 of the same year — in the Jurassic Fernie Formation.

Both wells encountered a complexly faulted and folded section.

The roads built to the well sites have been maintained by the Alberta Forest Service, and provide access to Eunice Creek sub-basin.

Present Work

Tri-Creek watershed investigation was initiated in 1965 by the Fish and Wildlife Division of the Alberta Department of Lands and Forests. The stated purpose of the study was to evaluate the effects of clear-cut logging on the physical, chemical, and biotic characteristics of western Alberta trout streams. The results of the investigation will be used to adjust or complement the ground rules of Forest Cutting Practices which currently apply to a large part of the Foothills belt (Fregren, 1967).

A request for a hydrogeological evaluation of the watershed was received by the Research Council of Alberta on February 1, 1967. Field work commenced July 1, 1967. The work resulted in the drilling of four wells, preparation of a bedrock geology map, and identification of glacial deposits.

Several trips were made to the basin during the winter of 1967-68, but field mapping of groundwater discharge features did not begin until May, 1968. The writer concluded field work July 23, 1968.

HYDROGEOLOGY

General Statement

Hydrogeology can be defined as the study of groundwater with particular emphasis given to its chemistry, mode of migration, and relation to the geologic environment (Davis and DeWiest, 1966). Dr. J. Tóth suggests that hydrogeology is the study of the chemical and physical processes and phenomena that result from interaction of groundwater and rock (personal communication, 1967).

In addition to consideration of the chemical and physical processes, considerable emphasis in this report is placed on the relationship of biological processes to groundwater flow.

Geology

Bedrock Geology

The bedrock is essentially covered by surficial deposits and vegetation. Outcrops are scarce — hence most of the information is derived from air photographs. The photogeologic interpretation is substantiated by field checks where possible.

Good exposures occur along the McLeod River and have been studied in detail by Dr. D. F. Stott (1963) and earlier workers. Some of Stott's stratigraphic units could be recognized in Tri-Creek basin where exposures are of limited extent (Map 1, in pocket).

Stratigraphy

Rocks of predominantly Upper Cretaceous age immediately underlie the surficial materials in Tri-Creek basin. Tertiary strata may be present in the upper part of the Brazeau Formation in the northern part of the study area.

The Alberta Group and the Brazeau Formation are the two major strati-

graphic units represented. The marine sequence of shales and sandstones, termed the Alberta Group, includes the Blackstone, Cardium, and Wapiabi Formations. The predominantly nonmarine strata of the Brazeau Formation have many as yet unsolved stratigraphic problems. Strata of ages corresponding to the Belly River, Edmonton, and Paskapoo Formations of the Prairies are not readily distinguished in the Foothills, and are therefore combined as the Brazeau Formation.

The Alberta Group strata are brought to the surface in the basin by the Brazeau thrust fault. The thickness of the section represented is estimated to be 2,400 feet.

Blackstone Formation: A maximum thickness of 450 feet of Blackstone Formation is represented adjacent to the Brazeau thrust. Lithologic characteristics of the section indicate that the Haven and Opabin Members are present.

The Blackstone Formation is dark grey shale with rusty weathering clay ironstone concretions. The contact of the Blackstone with the overlying Cardium Formation is not exposed.

Cardium Formation: The Cardium Formation, approximately 235 feet thick, is hard, resistant to weathering, and forms prominent ridges. Six members of this formation are named by Stott (1963); only the uppermost Sturrock Member is evident in outcrop. The Sturrock Member is massive, thickly bedded, slabby, rusty weathering, fine grained sandstone, with a well developed fracture system (Plate 1). The fossil *Cardium pauperculum* is present at the photographed locality.

The contact between the Cardium and Wapiabi Formations can be observed on Wampus Creek (Plate 1).

Plate 1. Contact between the Cardium and Wapiabi Formations. Dip 85° southwest. Note fracture system in the Cardium sandstone.

TABLE OF FORMATIONS

(after Stott, 1963, modified)

SERIES	GROUP	FORM.	MEMBER	DESCRIPTION
UPPER CRETACEOUS		BRAZEAU		green grey, non-calcareous sandstones and shales
	ALBERTA 2000-4100'	WAPIABI 1900'	NOMAD 100'	rusty weathering, rubbly shales grading upwards into greenish-grey shales and fine grained, thinly bedded sandstones
			CHUNGO 260'	fine grained, thickly bedded, light brown weathering sandstones, and dark grey siltstone
			HANSON 200'	dark grey, rusty weathering, blocky to rubbly shales, with reddish-brown weathering concretions
			THISTLE 700'	dark grey to black, calcareous, platy to fissile shales, weathers grey to light grey
			DOWLING 300'	dark grey, rubbly to platy shales, weathers rust, with reddish-brown concretions
			MARSHY-BANK 90'	dark grey, massive, argillaceous siltstone, with large reddish-brown concretions
			MUSKIKI 250'	dark grey, rubbly to platy shales, weathers rust, some concretions, slightly banded appearance
		CARDIUM 235'	STURROCK 25'	fine grained, thickly bedded sandstone, weathers rusty-brown
			LEYLAND 80'	dark grey to black, rubbly to blocky shales with large reddish-brown concretions
			CARDINAL	dark grey, massive argillaceous siltstone, with large reddish-brown concretions (may not be present in the area)
			KISKA	dark grey to black, rubbly to blocky shales with reddish-brown sideritic concretions (may not be present)
			MOOSE-HOUND 100'	greyish-green to brown, carbonaceous, rubbly shales, friable carbonaceous sandstones, thin coal beds, minor conglomerate
			RAM 30'	fine grained, thickly bedded sandstone, weathers rusty-brown
		BLACK-STONE 1900'	OPABIN 180'	dark grey, rusty weathering, blocky to rubbly shales, with reddish-brown weathering concretions
			HAVEN 270'	dark grey to black rubbly to platy shales, weathers rust, with yellow sulfur staining and fetid odor
			VIMY 550'	dark grey to black, calcareous, platy to fissile shales, weathers light grey to white (not present)
			SUNKAY 550'	dark grey, rubbly to platy shales, weathers rust, with some argillaceous siltstone large concretions (not present in the area)

Table 1.

Wapiabi Formation: The Wapiabi Formation (Malloch, 1911) includes all the beds between the underlying Cardium Formation and the coarse grained, greenish-grey sandstones of the Brazeau Formation. The dominant lithology is a dark grey shale.

Stott (1963) subdivided the Wapiabi Formation into seven members. Poor exposures precluded the identification of the members of the Wapiabi Formation in Tri-Creek basin.

The top of the Wapiabi Formation is picked on air photographs at the break in slope which indicates a change in lithology — from the easily eroded shale to the hard resistant beds of the Lower Brazeau Formation.

The resistant beds are sandstones, which were included in the Brazeau Formation by Lang (1947). The later work of Stott terms the beds the Chungo Member of the Wapiabi Formation.

The lithologic break between the massive bedded sandstones of the Chungo Member and the underlying shales is a more easily defined contact, both on air photographs and in the field. The reader is referred to Stott's Memoir on the Alberta Group for historical and exacting stratigraphic terminology, as of 1963.

Brazeau Formation: The Brazeau Formation was originally named by Malloch (1911) as 1,700 feet of nonmarine beds lying above the Wapiabi Formation. He did not define an upper boundary, and thicknesses ranging from 5,000 feet to 11,000 feet have been measured or estimated by subsequent workers. One such worker is Jensen (1966) who provides recent data on correlation with the plains region.

The Brazeau Formation consists of interbedded conglomerates, sandstones,

siltstones, and shales. The conglomerate and sandstone beds form prominent ridges, whereas the shale and siltstone, more easily eroded, form vegetation-covered valleys.

The conglomerate near the base of the formation (Plate 2) contains chert and quartzite pebbles in a light olive brown [5Y 5/6] (Oyama and Takehara, 1967), medium-grained, subrounded, noncalcareous matrix. The conglomerate is thick-bedded, and weathers into large slabs that exhibit a very dark reddish brown [10R 2/3] colour. The pebbles are loosely cemented and the matrix tends to break around them.

Sandstones of the Brazeau Formation are medium green-grey [5 6 6/1], white speckled, noncalcareous, fine to coarse grained, with subrounded to subangular grains, well cemented, and thickly bedded.

The shale and siltstone beds of the formation are dusky-brown [5YR 2/2] to grey [5B 6/0], micromicaceous, noncalcareous, with minor carbonaceous material.

The reader is referred to appendix B for a lithologic description of the upper 800 feet of Brazeau Formation encountered in the two B.A. et al. Kaydee wells.

The dip of the Brazeau Formation at depth in the two drilled wells is unknown. The drilled thicknesses are 4,105 feet at B.A. et al. Kaydee 14-12-48-23-W5M and 4,010 feet at the 5-7-48-22-W5M well one mile to the southeast.

Structure

The location of Tri-Creek basin with respect to the major structural features of the area is illustrated in figure 3.

The bedrock geology map (Map 1, in pocket) shows the structural features within the basin boundary.

Plate 2. Basal Brazeau Formation; chert pebble conglomerate; dip 56° southwest, strike N67°W.

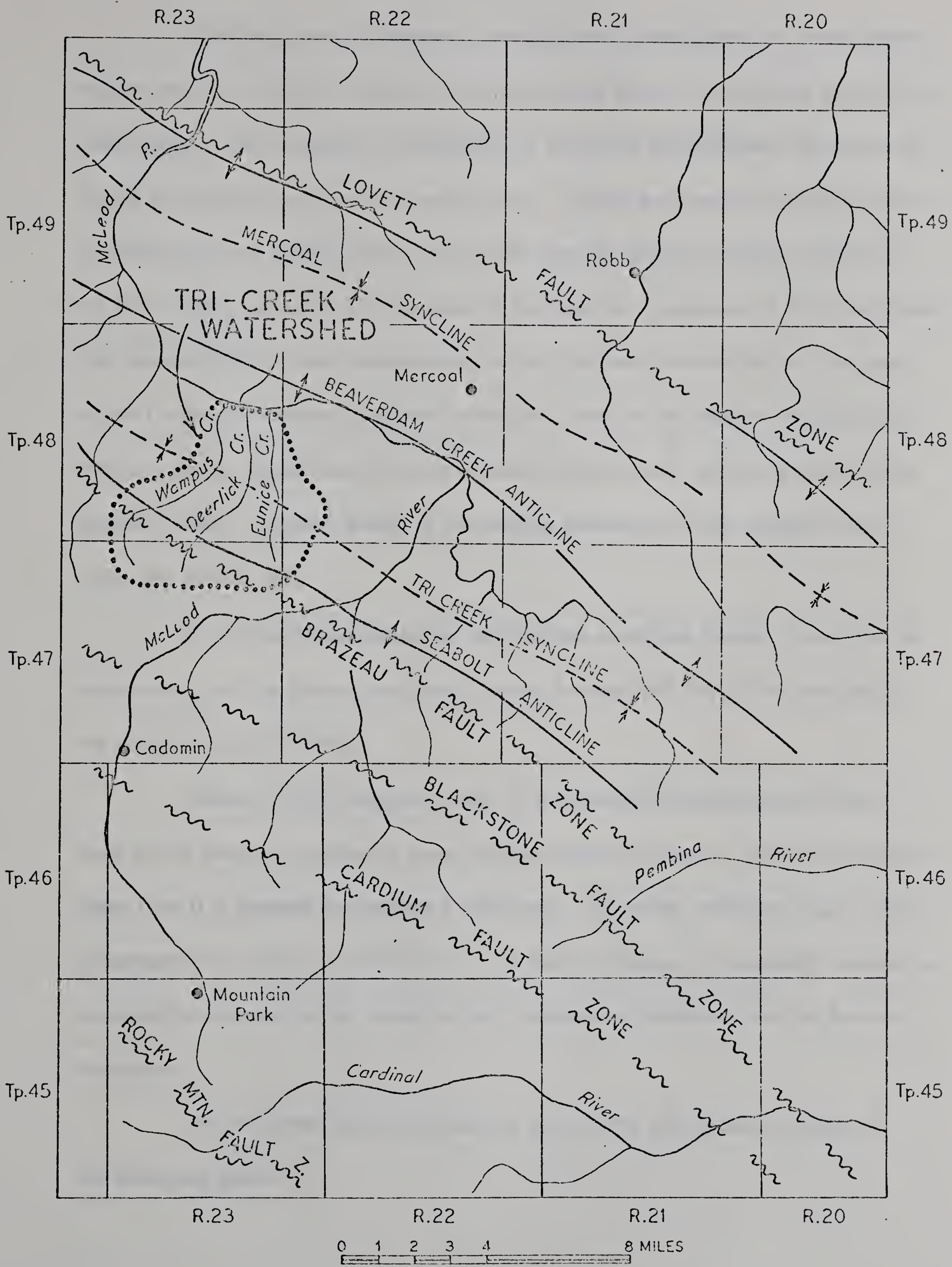


Figure 3. Location of Tri-Creek basin with respect to major structural features (after Lloyd, 1955, modified)

Tri-Creek basin is located in the disturbed Foothills belt of west-central Alberta which consists of a series of imbricate thrust blocks in which the strata have been folded. The intensity of deformation to which the Foothills belt has been subjected in the past increases from east to west. On the east margin open folds occur in Cretaceous and Tertiary strata, but to the west the folds are tighter and faults are more closely spaced. This increase in deformation is observed in Tri-Creek basin. The topographically lower northwestern part of the basin is underlain by the gently folded Cretaceous-Tertiary Brazeau Formation. West of the shallow anticline, the folds are tighter (Beaverdam Creek and Seabolt Anticlines), and are broken by the Brazeau thrust. This fault brings to the surface formations of the Alberta Group, which dip 70-85° SW.

To the southwest where the strata of the overlying Brazeau Formation are downfolded into the Brazeau syncline, the dip is about 60° SW. The west limb of the syncline dips 50-60°NE.

MacKay (1929) mapped a fault in the Brazeau Formation on the west flank of the Brazeau syncline in upper Wampus Creek sub-basin. This fault appears (Map 1) as it is located on MacKay's 1929 map. The writer could not discern field or topographic evidence for this fault. The fault, if present, is probably located in a vegetation-covered valley underlain by a sequence of shales within the Brazeau Formation.

The structural features present in each of the sub-basins are shown on the following table:

TABLE 2. STRUCTURAL FEATURES IN SUB-BASINS

Sub-basin	Brazeau thrust	Brazeau syncline	MacKay's fault
Wampus	yes	yes	yes
Deerlick	yes	no	no
Eunice	no	no	no

The Wampus Creek sub-basin is the most structurally disturbed.

Surficial Geology

The unconsolidated deposits lying on the bedrock of Tri-Creek basin are largely of glacial origin. Alluvial materials associated with present-day drainage channels are of minimal extent.

The isopachous map, constructed from seismic shot-hole information, gives a three-dimensional view of the distribution of the surficial deposits (Map 2, in pocket).

Glacial deposits

Till: Glacial till is unsorted, unstratified material, with a wide range in grain size, deposited directly from a glacier.

Two glacial tills are distinguished in the basin and for purposes of this report are named the local till and the Marlboro till (Roed, 1968). A third till which is confined to the McLeod River valley is, also for purposes of this report, termed the McLeod Valley limy till. Distinction of the tills is based on carbonate content and the presence or absence of quartzite pebbles.

The distribution of the tills is shown on figure 4. The local till covers most of the basin, the Marlboro till is limited to the lower part, and the McLeod Valley limy till is confined to the McLeod River valley outside the basin boundary.

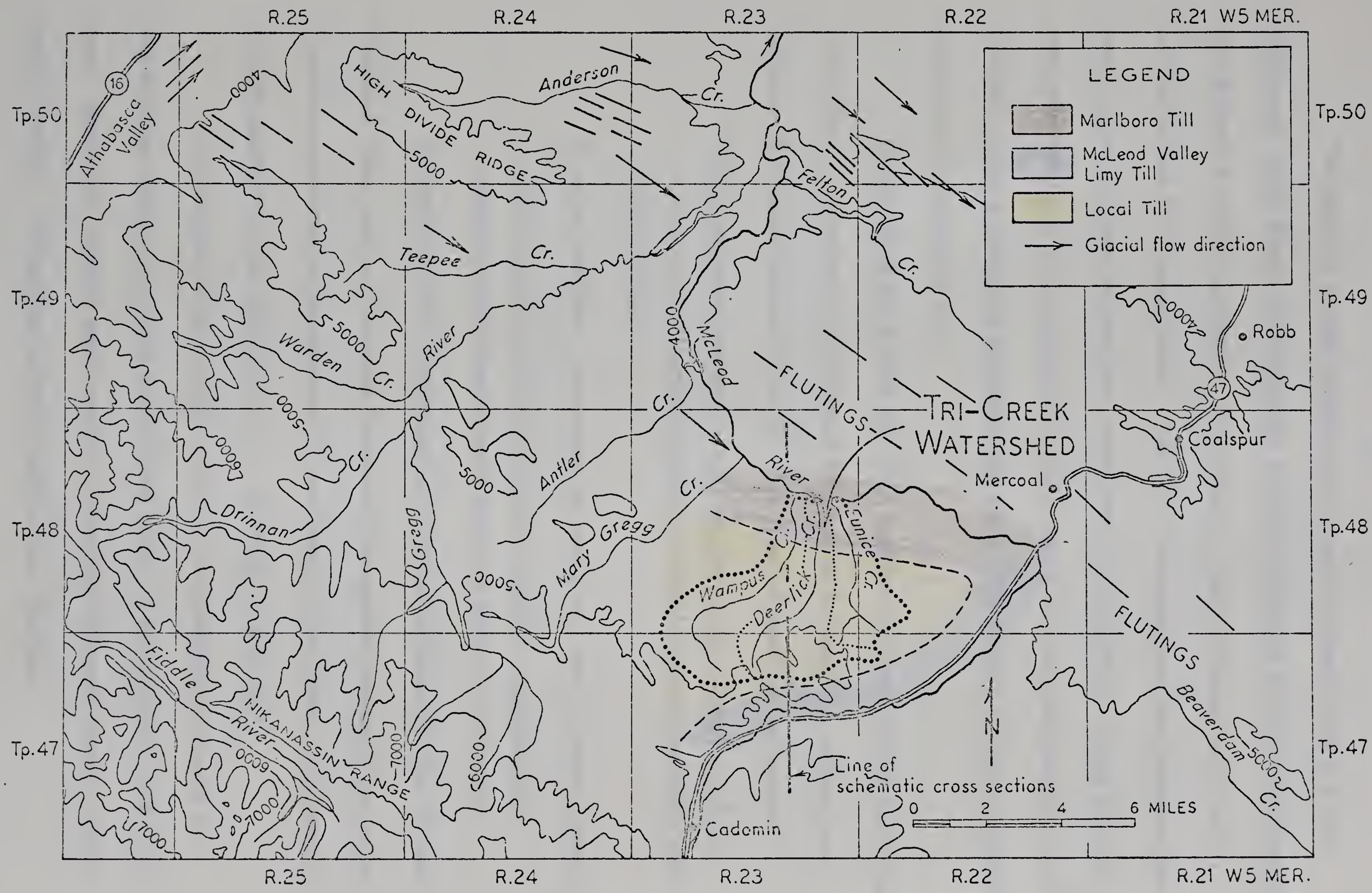


Figure 4. Glacial flow direction (after Roed, 1968, modified) and distribution of glacial tills

The local till is most commonly dusky yellow-brown [10YR 2/2], non-calcareous, sandy loam, with subangular cobbles and pebbles of local origin derived from Brazeau Formation sandstones. An attempt to obtain Atteberg limits for this material proved it to be non-plastic. The till is widespread and the sandstone fragments in the till appear to have been transported a short distance. Large Paleozoic carbonate erratics up to an estimated 50 cubic feet in size, and medium grey [N-3] in colour, occur sporadically throughout the basin. The erratics are fresh in appearance and rest on the local till.

The Marlboro till is olive [5Y 5/4], moderately stony, weakly plastic loam to clay loam. Quartzite is the dominant lithology of the boulders, cobbles, and pebbles in the coarse fraction of the till. Two types of quartzite are present:

1) light coloured quartzites - well rounded, hard, consisting entirely of fine to very fine grained quartz, probably derived from high level Tertiary gravels;

2) purple quartzites - subrounded to subangular, dark in colour (commonly reddish purple), coarse grained quartz pebbles, conglomeratic, probably derived from the main ranges of the Rocky Mountains.

The presence of the purple quartzite erratics indicates that this till is of Athabasca Valley origin. The name Marlboro till is applied because of similarities in pebble composition to the Marlboro till described by Roed (1968). This correlation was suggested in the field by Dr. J. A. Westgate in July 1967.

The McLeod Valley limy till is found in the east-west section of the McLeod River valley to the south of Tri-Creek basin. It is bluish-grey [5PB 5/1], stony, calcareous, contains many angular to subangular limestone erratics, and is sandy in texture. No rounded quartzite pebbles were observed.

The brief descriptions accompanying pebble count data (Tables 3, 4, and 5) and calcium carbonate determinations (Table 6) should serve to characterize the tills. A total of 207 pebbles was counted for each till.

An appreciation of the accuracy of the pebble counts to represent the appropriate till sheet is obtained by an estimate of probable error (Table 8) (Krumbein and Pettijohn, 1938, p. 472).

The values of probable error indicate that it is unlikely that the large differences in frequency of the different lithologies is due to chance alone. Three distinct materials are indicated.

Ice-contact stratified drift: Flint (1957) stated that three internal characteristics distinguish ice-contact stratified drift from outwash:

(1) extreme range and abrupt changes in grain size;

(2) included bodies of till;

(3) deformation of bedding.

The material identified as ice-contact stratified drift exhibits wide variation in grain size and deformed bedding. No inclusions of till were observed.

Two main areas of ice-contact deposits are outlined (Map 3, in pocket). The material, at the same elevation at both locales, consists of interbedded sands, silts, and gravels. Plates 3 and 4 illustrate the wide range and abrupt changes in grain size.

TABLE 3. PEBBLE TYPES IN LOCAL TILL

PEBBLE TYPE	NUMBER OF PEBBLES	PER CENT OF TOTAL
SILTSTONE - dark bluish grey [5 PB 3/1] noncalcareous, micromicaceous local bedrock material	70	34
CHERT - black [N 2/0] hard, well rounded, derived from Brazeau Formation	53	26
SANDSTONE - greyish olive [5 Y 5/2] medium to coarse grained local Brazeau Formation bedrock	51	25
CLAY IRONSTONE - vari-coloured, common rusty appearance, concretionary, local bedrock material	18	9
QUARTZ - greyish white [N 8/0] hard massive, subrounded	8	4
CONGLOMERATIC - greyish olive [5 Y 5/2] with some black chert pebbles	7	3
TOTAL	207	100

All pebbles in this till sample are of local origin

TABLE 4. PEBBLE TYPES IN MARLBORO TILL

PEBBLE TYPE	NUMBER OF PEBBLES	PER CENT OF TOTAL
QUARTZITE - light in colour, rounded, appears to be Tertiary gravel	50	24
QUARTZITE - dark in colour, subrounded, appears to be Lower Cambrian from the Athabasca Valley	29	14
TOTAL QUARTZITE	79	38
SILTSTONE - dark bluish grey [5 PB 3/1] noncalcareous, micromicaceous, local bedrock material	54	26
SANDSTONE - greyish olive [5 Y 5/2] medium to coarse grained local Brazeau Formation bedrock	50	24
CHERT - black [N 2/0] hard, rounded, derived from local Brazeau Formation	20	10
CLAY IRONSTONE - vari-coloured, common rusty appearance, noncalcareous, local bedrock material	4	2
TOTAL	207	100

TABLE 5. PEBBLE TYPES IN McLEOD VALLEY LIMY TILL

PEBBLE TYPE	NUMBER OF PEBBLES	PER CENT OF TOTAL
SILTSTONE - dark bluish grey [5 PB 3/1] noncalcareous, micromicaceous, local bedrock material	87	42
LIMESTONE - dark bluish grey [5 PB 4/1] very finely crystalline, clean, with fine calcite stringers	46	22
DOLOMITE - light grey [10 YR 8/2] very silty hard	28	14
LIMESTONE - greyish white [N 7/0] hard lithographic	13	6
LIMESTONE - yellowish grey [2.5 Y 6/1] very sandy hard	12	6
SANDSTONE - dull reddish brown [2.5 YR 5/3] very fine grained, hard, noncalcareous, not Brazeau "type"	10	5
CLAY IRONSTONE - vari-coloured, common rusty apperance, local bedrock material	10	5
CHERT - grey [N 4/0] hard	1	1
TOTAL	207	100

Total limestone + dolomite = 47.9%

TABLE 6. CALCIUM CARBONATE CONTENT OF SELECTED SAMPLES*

SAMPLE NO.	MATERIAL	LOCATION	PER CENT $CaCO_3$
H-1	glaciolacustrine	Upper Wampus Creek (4600')	.32
H-2	glaciolacustrine	Lower Eunice Creek	.39
H-3	glaciolacustrine	Lower Wampus Creek	.32
H-4	silt 84% < #230	Seepage Pit	4.71
T-6	glacial till	Mid-Deerlick Creek	.95
T-7	local till	Upper Wampus Creek (4800')	.29
T-8	McLeod Valley limy till	Trapper Creek road	9.79
T-9	Marlboro till	Lower Wampus Creek	.28

*for grain sizes < 2 mm

TABLE 7. DESCRIPTIVE CARBONATE CONTENT

PER CENT $CaCO_3$	VERBAL DESCRIPTION
2- 5	weakly calcareous
6-15	moderately calcareous
16-25	strongly calcareous
26-40	very strongly calcareous
40	extremely calcareous

TABLE 8. ESTIMATE OF PROBABLE ERROR

PER CENT OF SAMPLE	PROBABLE ERROR PER CENT
40	2.4
20	1.8
10	1.4
5	1.0

Plate 3. Glaciolacustrine silts over ice-contact stratified drift. Wampus Creek sub-basin, showing abrupt change in grain size.

Plate 4. Ice-contact stratified drift. Wampus Creek sub-basin.

Seismic shot-hole data show the deposits to be at least 90 feet thick at the Eunice Creek location, and over 56 feet on Wampus Creek. Drilling information near the Wampus Creek deposit indicates a thickness greater than 140 feet. The lower contact of this deposit is covered.

The topographic expression of the ice-contact deposits is masked by overlying glaciolacustrine silts, which makes classification as to land form difficult. A classification of environments of formation proposed by Fulton (1967, p. 14 and 34) indicates that these deposits are of the ice> water facies.

Glacial outwash: The outwash deposits occur in the lowermost part of the basin in association with more recent McLeod River alluvium.

The distinction between ice-contact stratified drift and outwash in Tri-Creek basin is based solely on the apparent lack of deformation and presence of conformable bedding of the outwash deposits. A distance of approximately two miles separates the two areas where deposits of the two types occur.

The areal extent of the outwash deposits is not great. The base of the outwash deposits was not observed; however, they are overlain by Marlboro till.

Deltaic deposits: The surficial geology map (Map 3) shows the extent of glaciofluvial deposits at the mouth of several meltwater channels. The composition of the deposits reflects the bedrock eroded from the channel.

Two deltaic deposits, both adjacent to the Wapiabi Formation subcrop, and down-basin from the mouth of a meltwater channel, are composed of subrounded, dark grey shale fragments. Similar deltaic forms are present at the mouths of meltwater channels cut into Brazeau Formation bedrock, but exposures are lacking.

The term delta is applied on the basis of the geographical location of

the form with respect to the meltwater channel, and on the basis of their expression on air photographs. In Fulton's classification these forms are of the water >ice facies.

Glaciolacustrine deposits: The glaciolacustrine sediments in Tri-Creek basin were identified by Dr. J. A. Westgate in July, 1967. Their distribution is shown on the surficial geology map (Map 3, in pocket).

The glaciolacustrine material is in the silt size range and is grey [5Y 6/1] when dry and light bluish-grey [10B6 7/1] when wet.

The glaciolacustrine silts are easily eroded; deep gullies and extensive slumps are present where vegetative cover has been removed (Plate 5).

Meltwater channels

The locations of observed meltwater channels in the Tri-Creek basin area are shown on the surficial geology map (Map 3, in pocket).

The channels which occur in Tri-Creek basin are direct overflows (Kendall, 1902, p. 481). These channels are a result of ponding of glacial meltwater and a subsequent rise in lake level until a basin divide is breached. The rapid outflow of water trenches the divide. The sediment derived from the trench is deposited in a delta at the mouth of the channel.

The channels located in the McLeod River valley are marginal overflows (Kendall, 1902). The interpretation is that this type of channel is formed by water flowing marginal to the valley glacier.

Elevations of the various channels are taken from a preliminary National Topographic Series map at the scale of 1:50 000 with a 100-foot contour interval.

Plate 5. Slumps associated with past logging operations on Lower Eunice Creek. The area is mantled with glaciolacustrine silt.

Deglaciation

The glacial history presented pertains to the part of Tri-Creek basin adjacent to the line of cross section (Fig. 4).

Three schematic cross sections combined with block diagrams (Figs. 5, 6, and 7) show a much simplified sequence of events that may explain the genesis of the glacial deposits along the line of section.

Figure 5 is a schematic block diagram which shows the area buried by glacial ice. Erratics of Paleozoic limestone found at the highest point in the basin substantiate this interpretation.

As the ice downwasted below the topographic highs ice-contact gravel, sand and glaciolacustrine silt were deposited into an ice marginal lake (Fig. 6 and Plate 3). These deposits occur at approximately the 4,600-foot elevation and were derived in part from adjacent nunataks.

The glacier that covered the local area retreated from the lower northern part of the basin. A deposit of glacial outwash located in the present McLeod River valley indicates that this may have been the case. This outwash material is overlain by Marlboro till and glaciolacustrine silt (Fig. 7).

The Marlboro till contains many erratics that are common to the Athabasca Valley (J. A. Westgate, personal communication, 1967). The contact of this till with the underlying outwash was covered.

The Marlboro-local till boundary is abrupt. The break from till containing only erratics of the Brazeau Formation to the diagnostic quartzite content of the Marlboro till occurs within a few feet. This boundary can be delineated on airphotos at the scale of one inch equals 1,000 feet and can be seen as a slight change

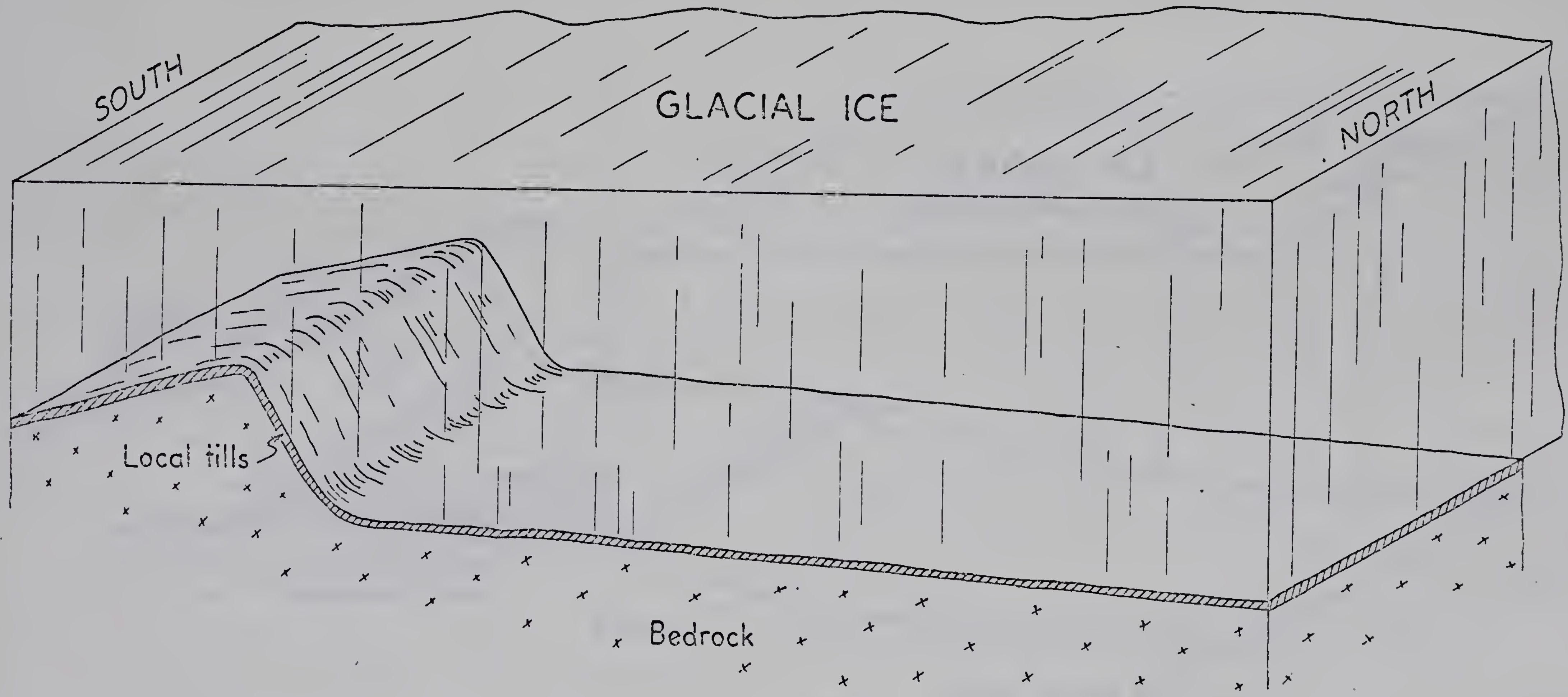


Figure 5. Schematic block diagram to show entire area buried by glacial ice

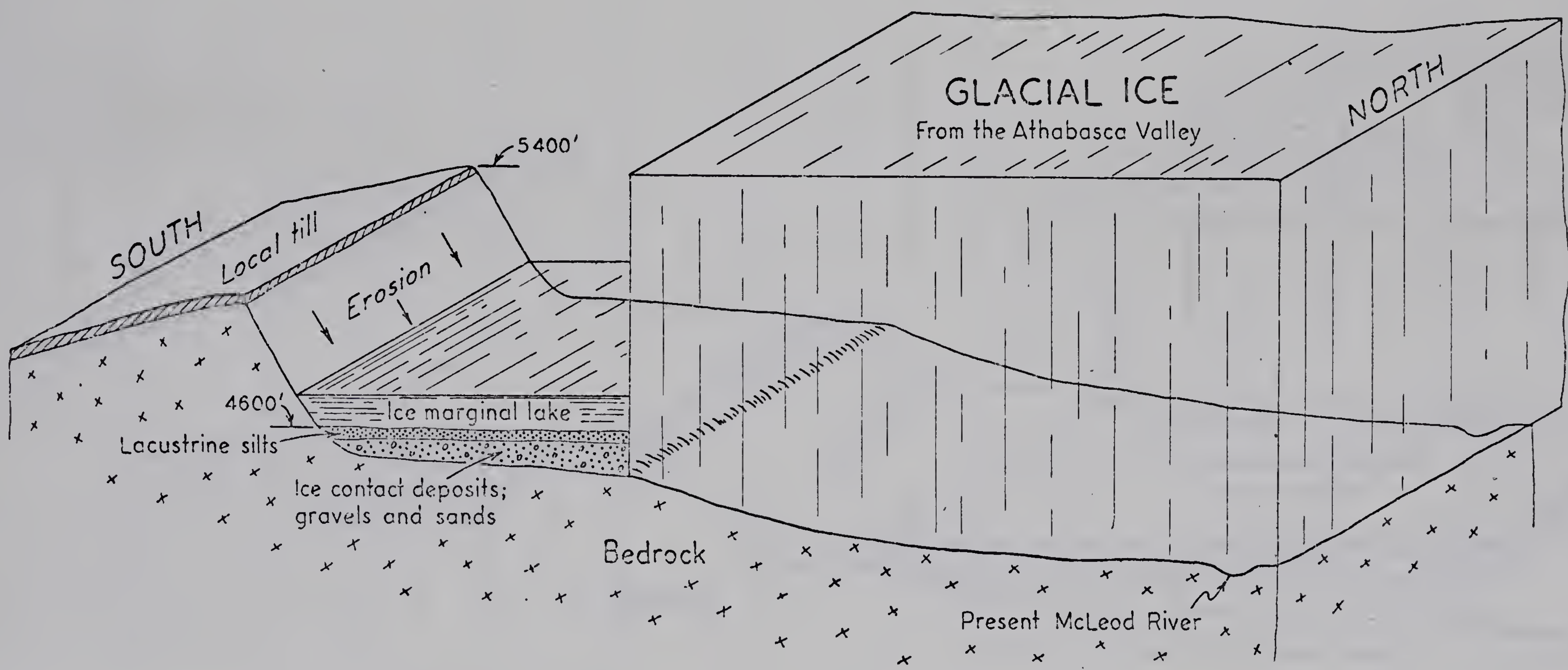


Figure 6. Schematic block diagram showing deposition of ice contact and glaciolacustrine deposits at 4,600' elevation

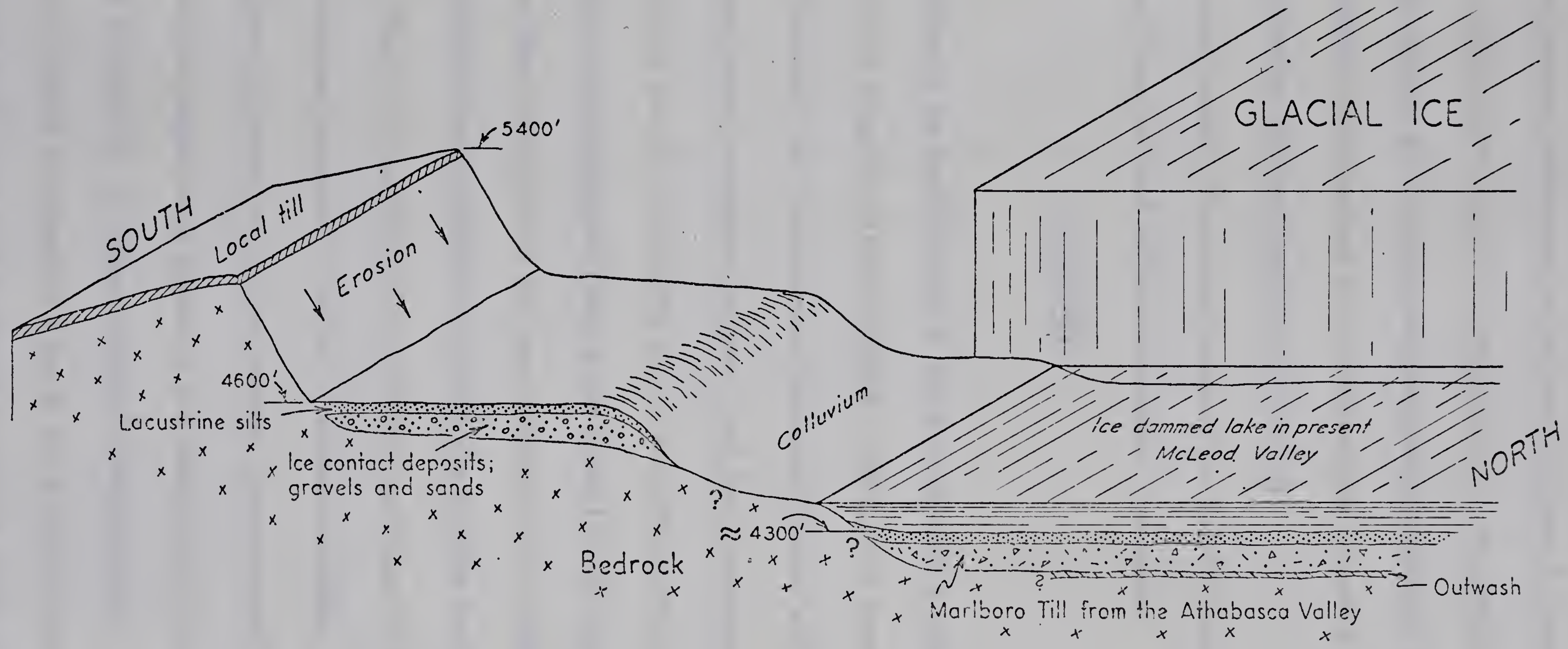


Figure 7. Schematic block diagram illustrating deposition of glaciolacustrine silts and Marlboro Till

in photo tone due to textural differences of the two tills (Map 3, in pocket). These field relationships indicate that the till was deposited over the gravels by a later ice advance. This may account for the high quartzite pebble content of the till (Table 4).

Deglaciation continued and a ice-dammed lake formed in the McLeod Valley. Glaciolacustrine silt was deposited over the till.

As previously stated, the contact between the glacial deposits in the lower part of the basin and those at the 4,600-foot elevation is covered.

Hydrology

Climate

The climate of the Foothills belt in the area of study is classified as humid microthermal and subarctic (Atlas of Canada, 1957). The letter code for this type is Dfc. Decoded, the D represents a rain-snow climate with cold winters. The f indicates precipitation throughout the year, and the c is indicative of a cool, short summer, with only one to three months with a mean temperature above 50°F.

A number of meteorological stations are located in Tri-Creek basin; however, data from these stations have not been extracted into readable form. The following precipitation and temperature information is taken from records for Entrance, Alberta (Fig. 1), on strike with and 30 miles northwest of the study area.

The information presented in table 9 is the best available. There is an approximate 1,000-foot elevation difference between Entrance and Tri-Creek basin which indicates that the temperatures presented are approximately two to three degrees Fahrenheit too high (A. V. Mann, personal communication, 1968).

Entrance, Alberta is located at a gap in the Rocky Mountains eroded in part by the Athabasca River. The area is subject to chinook winds during the

TABLE 9. TEMPERATURE AND PRECIPITATION DATA AT ENTRANCE, ALBERTA

ELEMENT	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	YEAR	Type of Normal
Mean daily temperature (°F)	12.6	16.6	25.0	37.7	47.7	53.5	58.7	56.0	49.3	40.4	26.8	16.6	36.7	1
Mean daily maximum temperature	24.0	29.6	37.1	51.2	62.5	67.3	74.0	71.1	63.8	53.2	37.5	27.6	49.9	1
Mean daily minimum temperature	1.1	3.6	12.9	24.2	32.8	39.6	43.3	41.0	34.8	27.5	16.0	5.6	23.5	1
Maximum temperature	61	66	71	82	93	94	100	92	91	85	70	64	100	4
Minimum temperature	-60	-52	-45	-32	10	20	27	27	-3	-13	-38	-53	-60	4
Mean rainfall (ins)	0.04	T	0.05	0.46	1.99	3.59	2.72	3.10	1.68	0.59	0.12	0.07	14.41	1
Mean snowfall	7.7	7.3	9.2	7.6	1.1	0.0	0.0	0.0	1.3	5.2	8.3	8.0	55.7	1
Mean total pptn.	0.81	0.73	0.97	1.22	2.10	3.59	2.72	3.10	1.81	1.11	0.95	0.87	19.98	1
No.of days with measurable rain	*	*	*	2	7	12	10	12	7	3	1	*	54	1
No. of days with measurable snow	7	6	6	5	1				1	3	5	5	39	1
No. of days with measurable pptn.	7	6	6	7	8	12	10	12	8	6	5	5	92	1
Maximum pptn. in 24 hrs.	1.25	1.00	0.90	1.16	2.12	3.07	2.00	2.68	2.09	1.60	1.25	0.90	3.07	1

Note: Data is 30-year average for the years 1931-1960.

winter months of the year. A similar situation exists at Tri-Creek basin. Chinook winds issuing from Cadomin gap, in part eroded by the McLeod River, cause anomalous temperatures in the winter months. On a trip to the basin in February 1968, temperatures in the 60-degree range were recorded. These high temperatures cause snowmelt and subsequent streamflow that is difficult to measure at the stream gauges as they are often inoperable during the winter months.

Stream Discharge

Stream discharge information is available for Wampus and Deerlick Creeks for the year ending September 30, 1967. Summary figures for the months of October and June to September are presented on table 10.

TABLE 10. STREAM DISCHARGE, WAMPUS AND DEERLICK CREEKS

Month	Discharge (cfs)	Discharge (ac ft/mo)
	Wampus Creek	
October	182.6	362
June	898.2	1,780
July	189.7	376
August	88.8	176
September	53.4	106
	Deerlick Creek	
October	106.6	211
June	576.5	1,140
July	114.4	227
August	49.6	98.4
September	23.1	45.8

Records from October to May are incomplete due to icing conditions at the artificial gauging stations. No records are available for Eunice Creek as the discharge installation was not completed until the fall of 1967.

Soils

Mr. Julian Dumanski of the Research Council of Alberta Soil Survey has traversed Tri-Creek basin at least twice and generously offered the following information.

Bisequa grey wooded in association with orthic grey wooded soils occur in areas with glacial till as parent material.

The glaciolacustrine silts support an orthic grey wooded profile. Areas with slopes in excess of 30 per cent have brown wooded in association with orthic grey wooded soils. Organic soils and gleyed profiles of the aforementioned soils occur in areas of groundwater discharge.

Geomorphology

Topography

Tri-Creek basin is located in the northwest-trending, elongate ridges and valleys of the Foothills belt.

The basin has a local relief of 1,400 feet. The highest elevation is 5,524 feet in Deerlick sub-basin. The elevation of the junctions of the three creeks with the McLeod River is approximately 4,130 feet above sea level.

The general topographic appearance of the central part of the basin is shown by Plate 6. The photo is taken looking northeast across the strike ridges of resistant members of the Brazeau Formation. Deerlick Creek has cut a transverse valley through resistant strike ridges.

Amphitheatre-shaped depressions are common geomorphic phenomena associated with groundwater discharge areas on steep slopes. These depressional features grade to a terraced effect in areas of more gentle slopes. The size of the

Plate 6. Deerlick Creek valley and meadow associated with ground-water discharge. View northeast.

features has a wide range. The best developed amphitheatre is observed on a slope of approximately 45°, just southwest of piezometer nest number 4 (Map 4, following page 89). The feature has estimated dimensions of 30 feet x 40 feet, with a 10-foot high back wall. The floor of the amphitheatre supports phreatophytic vegetation. It is suggested that this type of feature be considered an end point of a continuous series to the terracing present on very gentle slopes.

The margins of the gentle slope features are difficult to discern. The maximum observed dimensions are 120 feet x 140 feet at a groundwater discharge area in Eunice Creek sub-basin. The minimum observed area for this type of feature is three square feet.

It is strongly suspected that the cause of the features is groundwater discharge; however, plate 7 shows a rock slide with the dimensions 34 feet x 26 feet, with a 6-foot back wall on a slope of approximately 30°. No evidence of an excess of groundwater is observed.

Plate 5, in the surficial geology section of this report, shows a slump, a common geomorphic phenomenon in areas overlain with glaciolacustrine silts. The slumps and associated deep gullies occur at areas in the basin that have undergone disturbance of the vegetative cover by logging and seismic operations.

Drainage and aspect

The main streams in Tri-Creek basin exhibit a subparallel drainage pattern (Zernitz, 1932). The tributaries in the upper part of the basin are controlled by the northwest strike of the bedrock geology. The streams flowing in the strike valleys are underfit.

Tri-Creek basin is part of an over-all trellis drainage pattern in this

Plate 7. Rock slide (34'x26'x6') in Wampus Creek sub-basin. General slope is towards the observer at approximately 30°.

section of the Foothills. This pattern has been slightly modified by glaciation; particularly by the development of meltwater channels which correspond to strike valleys.

Tri-Creek basin has a predominant north facing aspect. This, coupled with the subparallel drainage pattern contributes to a maintenance of snow cover in the spring of the year.

One traverse early in May 1968 up to the southwest basin divide was made in waist deep snow. The walk down the south facing slope into Trapper Creek valley was made on dry ground.

Geometric factors

The computed values for various geometric factors pertaining to the three sub-basins and Tri-Creek basin appear in Table 11. The measurements are taken from a map at the scale of four inches equals one mile with a contour interval of 100 feet.

The map accuracy is fair. The map is a photographic enlargement of a compilation of two preliminary National Topographic series sheets at the scale of 1:50 000. The two Cadomin sheets were constructed from air photographs taken in 1943 and 1945 with field control in 1959. Correlation of contour values between the two sheets is poor. This was corrected in the maps used in this report. Modification of the topographic map on the basis of information obtained by close scrutiny of air photographs further improved map accuracy.

Area: The areas are planimeter measurements of the map at the scale of four inches equals one mile.

Stream order: All three sub-basins are fourth order basins. The order number is directly proportional to relative basin dimensions, channel size, and stream

TABLE 11. GEOMETRIC FACTORS

BASIN OR SUB-BASIN	AREA (sq mi)	STREAM ORDER	NO. OF STREAMS	BIFURCATION RATIO	LENGTH (miles)	STREAM FREQUENCY N/A	RELIEF RATIO R/L ft/ft	DRAINAGE DENSITY ΣL/A mi/sq mi
EUNICE CREEK	6.63	1	50	4.55	15.5			
		2	11	3.67	8.0			
		3	3	3.00	2.3			
		4	1		4.1			
Total			65		30.9	9.8	.06	4.7
DEERLICK CREEK	5.80	1	49	4.90	9.4			
		2	10	5.00	2.9			
		3	2	2.00	2.6			
		4	1		4.1			
Total			62		19.0	10.7	.05	3.3
WAMPUS CREEK	10.33	1	93	3.30	26.0			
		2	28	5.60	13.6			
		3	5	5.00	3.4			
		4	1		3.3			
Total			127		46.3	12.3	.04	4.5
TRI CREEK BASIN	22.76	1	192	3.90	50.9			
		2	49	4.90	24.5			
		3	10	3.30	8.3			
		4	3		11.5			
Total			254		95.2	11.0		4.1

discharge (Strahler, 1957).

Despite differences in bedrock geology and structural disturbance, the stream order and frequencies are similar. The low drainage density value of 3.3 for Deerlick sub-basin correlates with its elongate shape. Streams do not have the opportunity to develop a system of long first order segments.

Commonly streams of lower order are present in greater numbers than streams of higher order. The ratio of the number of streams of a given order to the number of streams of the next higher order is termed the bifurcation ratio. It is an indicator of the measure of geologic control of drainage (Strahler, 1957, p. 914). Bifurcation ratios for the basin and sub-basins range from 3.3 to 4.9 for first order to second order streams, and 3.67 to 5.6 for second to third order streams.

The highest bifurcation ratio of 5.6 for the Wampus Creek sub-basin is greater than the common range of 3 to 5 for areas where geologic control of drainage is lacking. This high value is explained by the fact that Wampus Creek flows, in part, in a strike valley. Strahler (1964) predicted values greater than 5 for strike controlled basins.

Drainage density: Drainage density is defined as the ratio of the sum of the stream lengths to the area of the basin. The low values indicate the region has resistant bedrock, permeable subsoil materials, and a dense vegetation cover (Strahler, 1964).

Stream frequency: Stream frequency is the ratio of the total number of streams to basin area. The relationship between drainage density and stream frequency is reported by Melton (1958) to be:

$$F = 0.694D^2 \qquad (1)$$

where F = frequency

D^2= drainage density.

The values of F/D^2 for the Tri-Creek basin range from .44 to .61. The departure from Melton's mean value of .694 may be because of the derangement of drainage by glaciation.

Relief ratio: The relief ratio is the ratio of local relief to the length of the basin, as measured along a straight line.

The geometric factors presented in the preceding paragraphs may have little comparative value because of the lack of application of this type of analysis to glaciated topography up to the present time.

Vegetation

The vegetation of the Tri-Creek basin area is classified as sub-alpine forest (Moss, 1955). The subalpine region is dominated by coniferous vegetation.

The forest cover map (Fig. 8) shows the distribution of tree types. Lodgepole pine (*Pinus contorta*), white spruce (*Picea glauca*), black spruce (*Picea mariana*), and alpine fir (*Abies lasiocarpa*) are the most numerous trees represented.

The forest cover map, prepared by the Alberta Department of Lands and Forests, is coloured to indicate a relationship between tree type and natural groundwater recharge and discharge conditions.

The terms natural groundwater recharge and discharge are defined as follows (Freeze, 1967):

> "Natural groundwater recharge refers to the motion of water that percolates down through the unsaturated zone to the water-table and actually enters the dynamic groundwater flow system.
>
> "Natural groundwater discharge refers to the motion of water

TABLE 12. FOREST CLASSIFICATION LEGEND

Recent clear cut	CC	Hay meadow	
Recent partial cut	PC	Marsh, bog	
Potentially productive	PP	Treed muskeg	
Burned over area		Barren above timberline	
Recent windfall		Barren rock	
Stunted		Agricultural lands	
Bushland	33	Grassland	

DENSITY		HEIGHT		SUB-TYPE	
A	Sparsely stocked	1	up to 30 feet	Fa	Alpine fir
B	Medium stocked	2	31 to 60 feet	Pi	Lodgepole pine
C	Fully stocked	3	61 to 80 feet	Sb	Black spruce
D	Overstocked	4	81 feet and over	Sw	White spruce
				Ss	mixed Sw and Sb
				Fb	Balsam fir

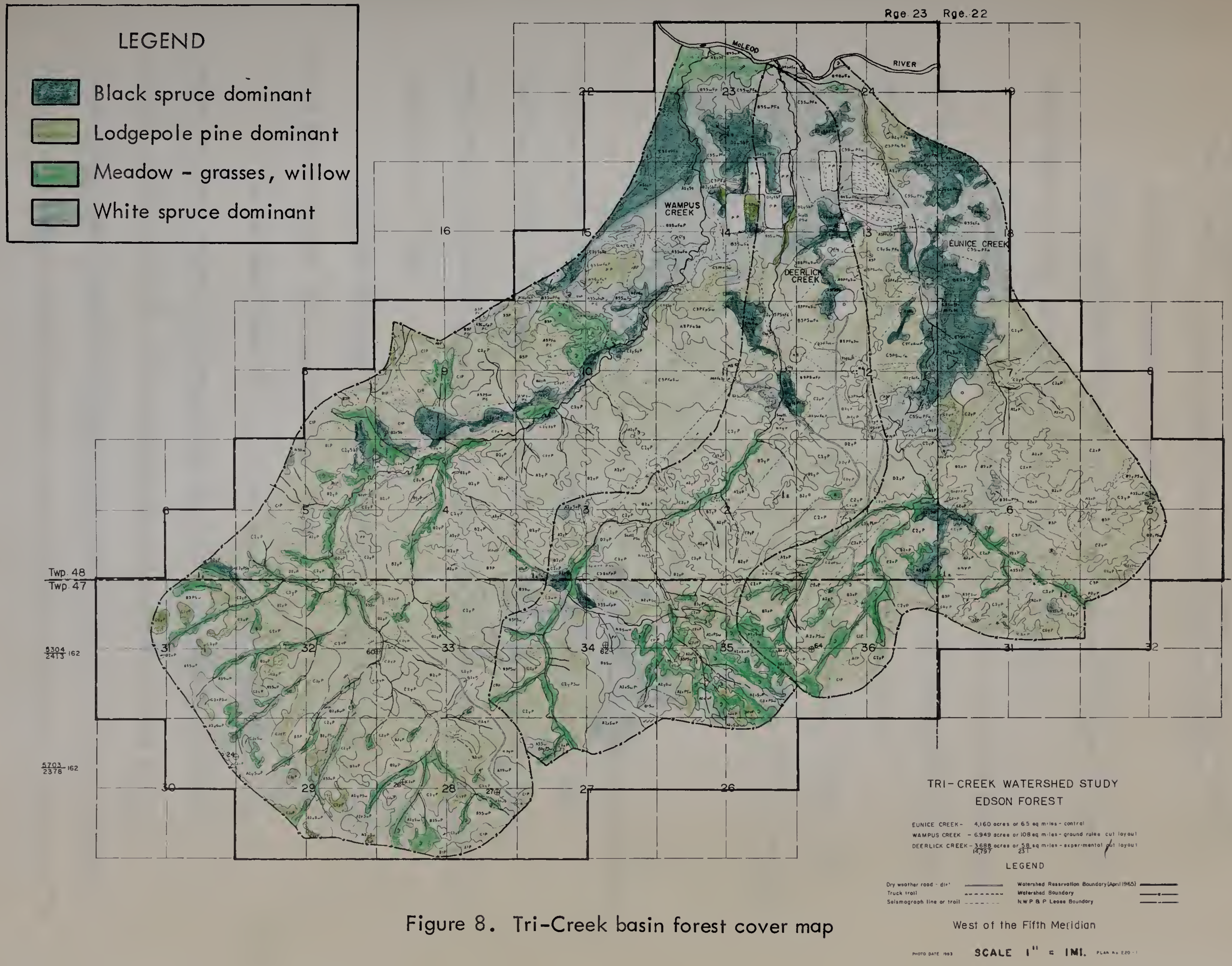


Figure 8. Tri-Creek basin forest cover map

that is removed from the dynamic groundwater flow system by means of stream baseflow, springs, seepage areas, and evapotranspiration."

Vegetation indicative of recharge conditions

Plant associations observed in Tri-Creek basin match those of Vereiskii and Vostokova (1963), as indicated in the following paragraphs.

Vereiskii and Vostokova state that an association of pine with broom grass, bearberry, etc., occurs on the summits and upper slopes of ridges and hills, and indicates the water table is at least 9.8 feet below the ground surface.

The areas covered by white spruce exhibit a spruce-pine, bilberry, and green moss association indicative of a depth to water table of 10 to 16 feet (Vereiskii and Vostokova, 1963).

Vegetation indicative of discharge conditions

The black spruce area has a spruce-fir association with haircap and sphagnum moss, which indicates a water table depth of 2 to 5 feet (Vereiskii and Vostokova, 1963). Black spruce and alpine fir occur only in this area. These species require considerably more moisture than lodgepole pine (D. Fregren, personal communication, 1968).

The interpretation (Fig. 9) is that the lower part of Tri-Creek basin is a broad zone of vegetal discharge (Meinzer, 1923).

The meadows (Plate 6) occur in the upper part of the basin, where the valley walls are steeper. The steep slopes result in an increase in intensity of groundwater flow (Fig. 10). The meadows support the growth of sedge (*Carex*), willow (*Salix*), and swamp birch (*Betula pumila*) which require very moist conditions. The species of sedge were not determined, but Vereiskii and Vostokova (1963) state

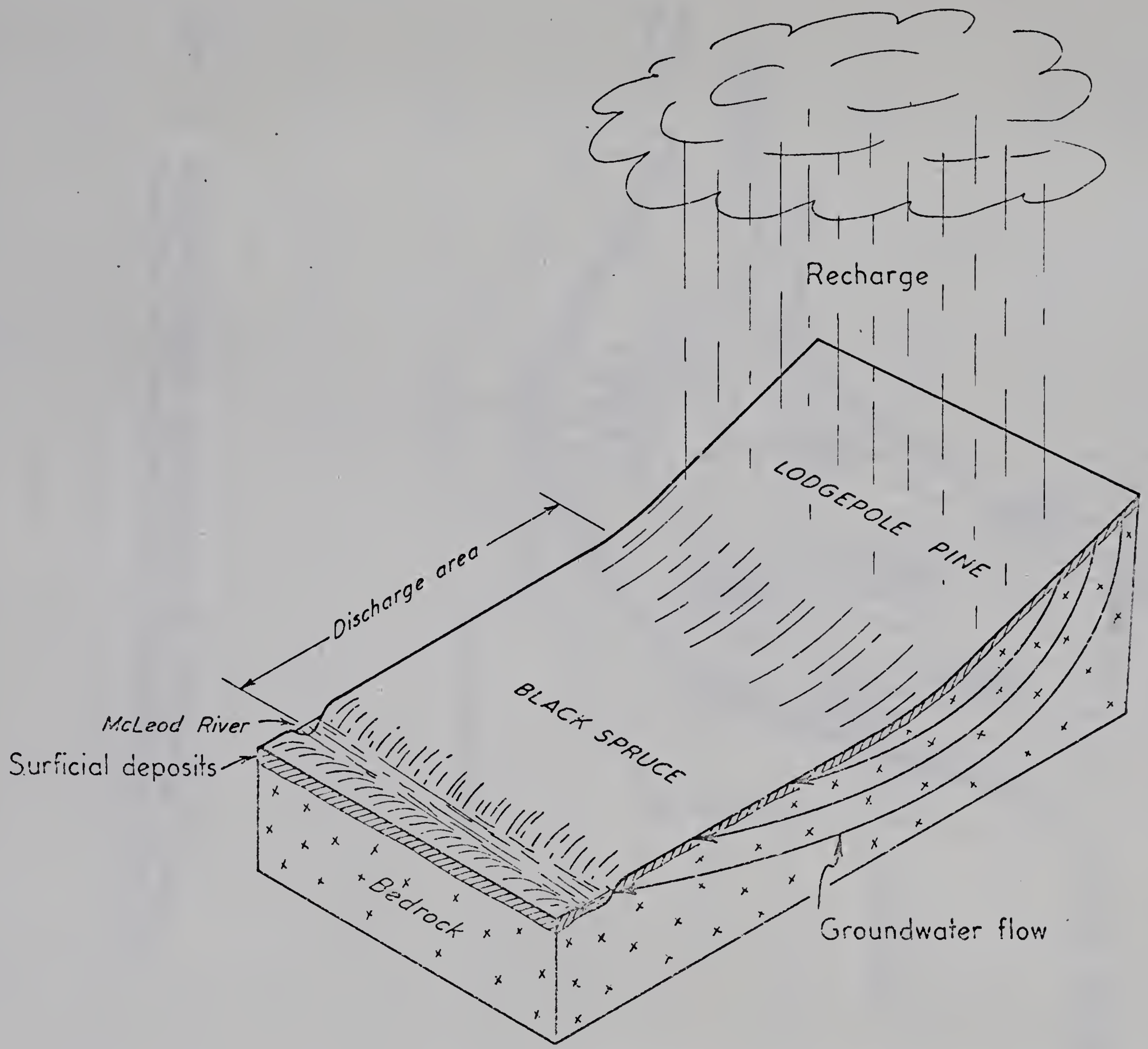


Figure 9. Schematic diagram to demonstrate the relationship between vegetation and groundwater flow in the lower part of the basin

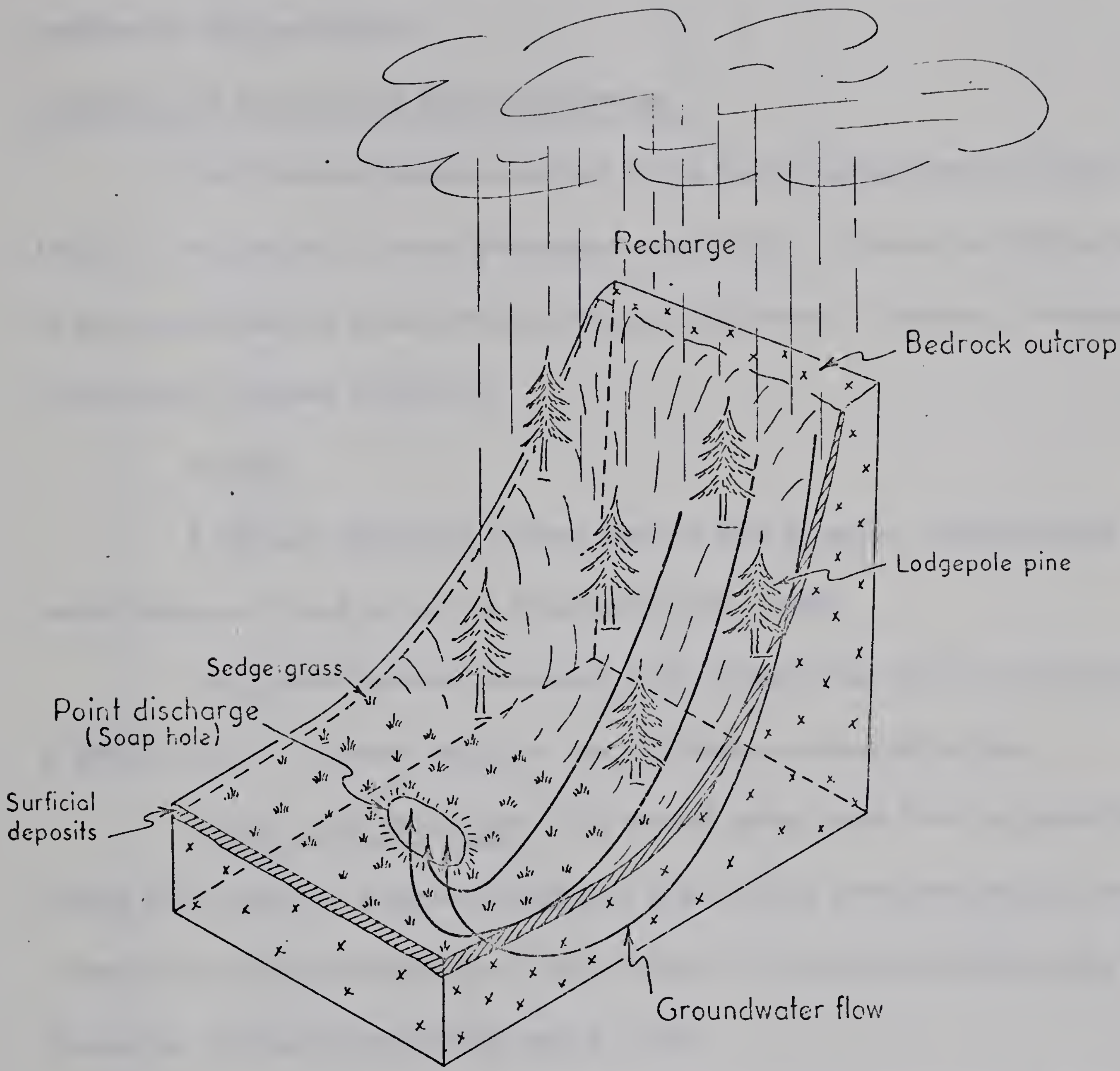


Figure 10. Schematic diagram to demonstrate the relationship between vegetation and groundwater flow in the upper part of the basin

that the sedge Carex vesicaria requires that the water table be not deeper than 2 feet. This indirectly indicates that the water table is close to the surface in the meadows of Tri-Creek basin.

Description of Groundwater Discharge Features

The discharge features observed during field investigations are listed in table 13. An overlay of the air photograph mosaic (Fig. 11) shows the distribution of springs and areas of groundwater recharge and discharge. The areas, as measured by planimeter, appear in Table 14.

Springs

A spring is defined as a place where a flow of water, issuing through a natural opening in rock or soil, is discernible (Tóth, 1966).

Two types of springs are present in Tri-Creek basin, and are illustrated in plates 8 and 9. They are springs of the rock debris and soaphole types.

Spring - rock debris type: This type of spring issues from the ground at a change from a steep to a gentle topographic slope, and is characterized by a string of angular to subangular boulders of local bedrock in the channel leading away from the spring. The ground around the spring is firm.

The measured discharge rate for this type of spring ranges from less than one half to greater than six gallons per minute. The rate of flow for individual springs is variable in response to changes in the weather.

Spring - soaphole type (Clissold, 1967): This type of spring issues from a vertical cylindrical hole and is located in a local area of flat topography. Only organic soil and silt are present marginal to the springs; boulders are lacking. The ground around the spring is in a quick condition caused by upward moving ground-

TABLE 13. GROUNDWATER DISCHARGE FEATURES

MAP LOCATION	TYPE OF DISCHARGE	AREA OF FEATURE (square feet)	DEPTH (Feet)	ESTIMATED DISCHARGE (Gallons per Minute)	REMARKS
1	Spring of soap hole type	9 x 9 = 81	4.5	1.5	slumping in channel to creek
2	Spring of soap hole type	3 x 4 = 12	4	< .5	slumping in channel to creek
4	Seepage pit	120 x 140 = 16,800	6	10	arcuate pit - slumping
5	Spring of rock debris type	4 x 2 = 8	7.5	< .5	1' deep channel reaches creek
6	Spring of soap hole type	4 x 3 = 12	>10	< .5	1' deep channel does not reach creek
7	Large feature may be soap hole type	45 x 45 = 2025	-	?	circular pond grdwtr fed
8	Spring of soap hole type	3 x 3 = 9	-	1	bubbles in evidence
9	Spring of soap hole type	4 x 3 = 12	-	< .5	
10	Spring of soap hole type	5 x 5 = 25	-	< .5	
11	Spring of soap hole type	3 x 5 = 15	-	1	flow of creek increased
12	Algae seepage	3 x 2 = 6	< 1	< .5	ephemeral

TABLE 13.

MAP LOCATION	TYPE OF DISCHARGE	AREA OF FEATURE (square feet)	DEPTH (Feet)	ESTIMATED DISCHARGE (Gallons per Minute)	REMARKS
13	Ditch seepage	diffuse	-	1	located just below Eunice divide
14	Broad seepage	diffuse	-	>1	located at Eunice divide
16	Ditch seepage	diffuse	-	<1	Trapper creek drainage
17	Spring of soap hole type	6 x 8 = 48	8.5	>2	material in hole very loose
19	Mossy seep	2 x 2 = 4	<1	$<.5$	
21	Spring of soap hole type	3 x 4 = 12	4	<1	
23	Spring of rock debris type	1 x 2 = 2	-	1	
28	Spring	4 x 3 = 12	-	3	many bubbles in evidence
30	Spring of soap hole type	2 x 2 = 4	-	$<.5$	old seismic shot hole
32	Line seepage	2 x 15 = 30	-	$<.5$	
34	Spring of rock debris type	2 x 1 = 2	-	$<.5$	in Wapiabi shales
37	Algae seep	3 x 3 = 9	1	$<.5$	
39	Spring of rock debris type	1 x 4 = 4	-	1	

TABLE 13.

MAP LOCATION	TYPE OF DISCHARGE	AREA OF FEATURE (square feet)	DEPTH (Feet)	ESTIMATED DISCHARGE (Gallons per Minute)	REMARKS
40	Spring of soap hole type	3 x 4 = 12	3.5	.5	
41	Spring of soap hole type	4 x 5 = 20	4	1	
44	Spring of rock debris type	1 x 3 = 3	-	>6	
48	Spring of rock debris type	20 x 30 = 600	-	2	
49	Spring		-	< .5	old seismic shot hole ?
52	Spring of rock debris type	1 x 2 = 2	-	< .5	formed tibutary stream
53	Spring of rock debris type	1 x 3 = 3	-	< .5	formed tributary stream
56	Broad seepage	diffuse	-		
57	Spring of soap hole type	2 x 2 = 4	-	< .5	
58					
59	Spring of soap hole type	5 x 5 = 25	4.5	1	

TABLE 13.

MAP LOCATION	TYPE OF DISCHARGE	AREA OF FEATURE (square feet)	DEPTH (Feet)	ESTIMATED DISCHARGE (Gallons per Minute)	REMARKS
60	Spring of soap hole type	10 x 10 = 100	5.2	1	
61	Spring of soap hole type	12 x 12 = 144	7.3	1	
62	Spring of soap hole type	3 x 3 = 9	4.2	< .5	
65	Spring of soap hole type	1 x 2 = 2	-	< .5	
67	Spring of soap hole type	10 x 10 = 100	>.5	>1	wavy ground
68	Spring of rock debris type	60 x 20 = 1200	-	1	terraced feature
72	Spring of rock debris type	1 x 4 = 4	-	< .5	
76	Seepage on cut line		-	minute	
90	Spring of rock debris type	1 x 3 = 3	-	< .5	ponded in millsite
91	Bank seepage		-	< .5	millsite

LEGEND

Area of groundwater discharge . .

Spring . . . .

Glaciolacustrine deposits . . . .

Glaciofluvial deposits . . . . .

Meltwater channel and elevation .

Meltwater flow direction . . . .

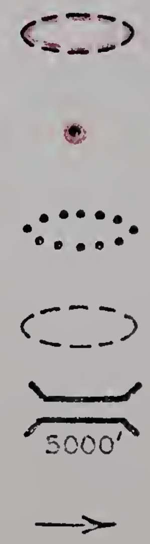


Figure 11. Airphoto mosaic with overlays

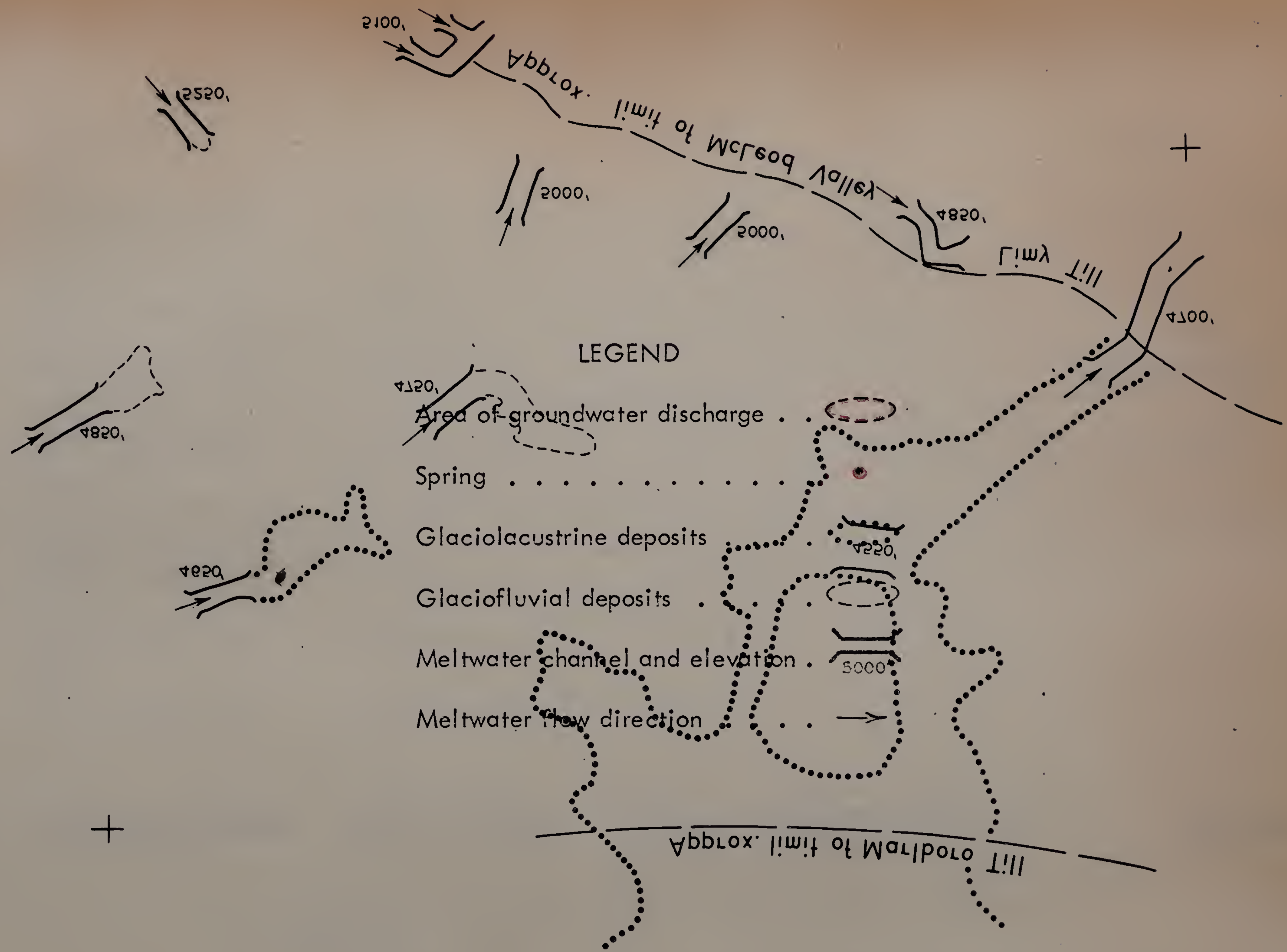

LEGEND
Area of groundwater discharge
Spring
Glaciolacustrine deposits
Glaciofluvial deposits
Meltwater channel and elevation
Meltwater flow direction
5000'
Approx. limit of McLeod Valley Limy Till
Approx. limit of Marlboro Till
5100'
5250'
5000'
5000'
4850'
4700'
4750'
4850'
4850
4550'

Figure 11. Airphoto mosaic with overlays


LEGEND
Area of groundwater discharge
Spring
Glaciolacustrine deposits
Glaciofluvial deposits
Meltwater channel and elevation
Meltwater flow direction
Approx. limit of McLeod Valley
Limy Till
Approx. limit of Marlboro Till
5100'
5250'
5000'
5000'
4850'
4850'
4700'
4750'
4650'
4550'
5000'

Figure 11. Airphoto mosaic with overlays

TABLE 14. MEASURED AREAS OF GROUNDWATER RECHARGE AND DISCHARGE

BASIN OR SUB-BASIN	AREA (sq mi)	DISCHARGE (sq mi)	RECHARGE (sq mi)	PER CENT DISCHARGE
TRI CREEK	23.1	5.97	17.13	25
WAMPUS CREEK	10.33	1.50	8.83	14.6
DEERLICK CREEK	5.8	1.46	4.34	25.1
EUNICE CREEK	6.63	2.19	4.44	33.0

These figures were obtained by planimeter from an overlay of a 1"=1 mile airphoto mosaic.

Plate 8. Spring of rock debris type. Lower Deerlick Creek. Discharge feature #53.

Plate 9. Spring - soaphole type. Wampus Creek. Pipe is 1 inch x 10 feet. Depth of hole 7.3 feet. Discharge feature #61.

water (Plates 9 and 10). A definition of the term "quick condition" follows in the description of specific discharge areas in the Wampus Creek sub-basin.

The rate of measured discharge ranges from less than one half to two gallons per minute. This type of discharge feature is less variable in response to climatic events than the springs of the rock debris type.

Groundwater seepage

Groundwater seepage is a diffuse movement of water on to the surface, at a rate which is not discernible, but is equal to or exceeds the rate of evapotranspiration (Clissold, 1967).

The major type of seepage observed in Tri-Creek basin is associated with the meadow environment(Plate 6).

Marginal to all of the springs of the soaphole type there is an area of groundwater seepage. The seepage zone is surrounded by a broader area of hummocky ground. The boundaries between the zones are gradational (Fig. 12, Plates 11 and 12).

Hummocky ground

This term is used to describe the hummocky surface of the ground found in association with groundwater discharge in the meadow environment. The hummocks, hemispherical in shape, range in size from six inches to one foot in diameter, are spaced two or three inches apart, and are covered with sedge.

At many localities the hummocky ground is "quicked" by upward moving groundwater, wet, depresses easily under a man's weight and is difficult to cross on foot.

Plate 10. Discharge feature #61. A similar feature (#60), not visible, is located above the boy's head. Note the terraced effect.

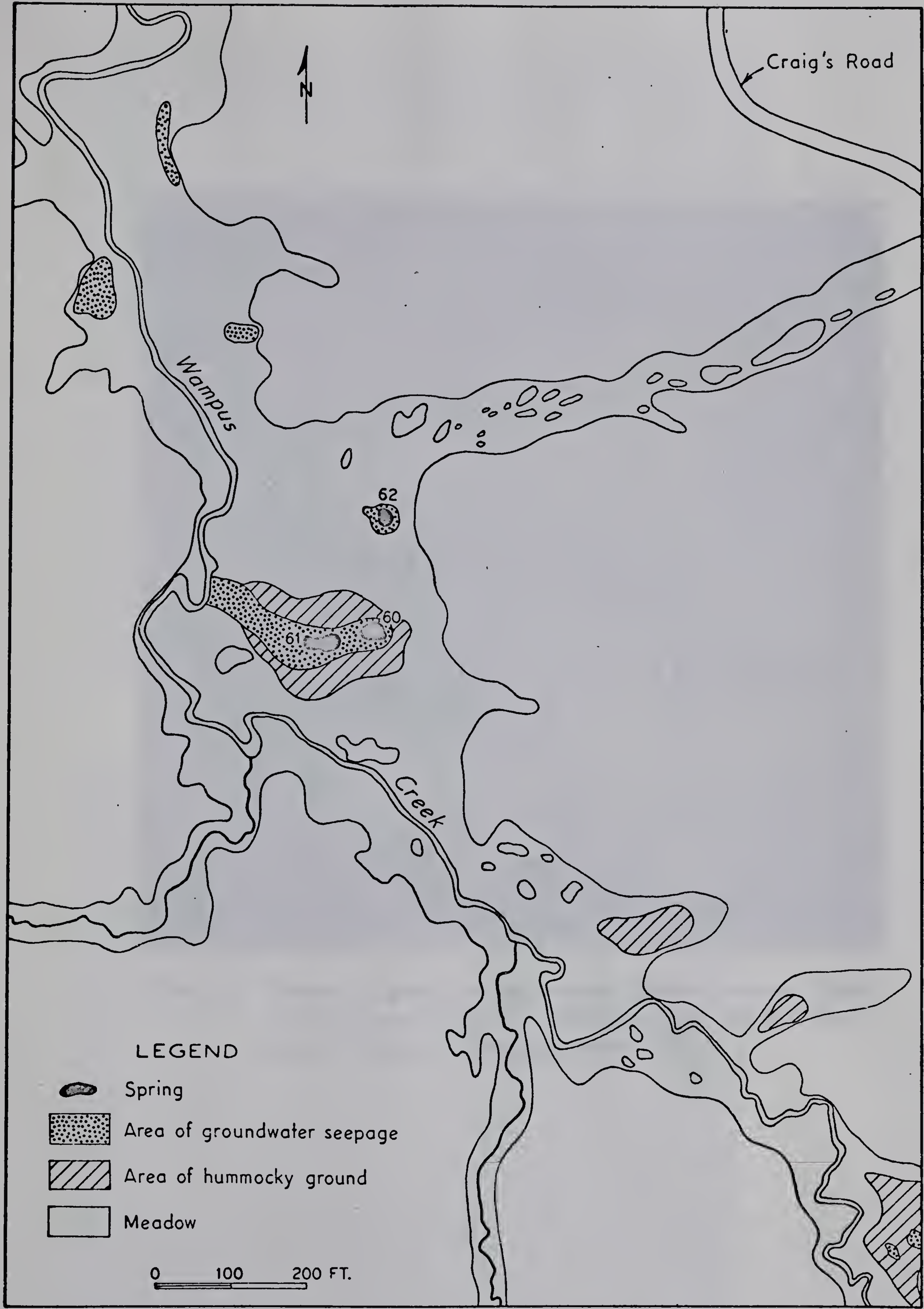


Figure 12. Groundwater discharge features, Wampus Creek sub-basin

Plate 11. Hummocky ground of groundwater discharge area. Note grass and stunted spruce. The vegetation mat was floating in this area. Discharge feature #67.

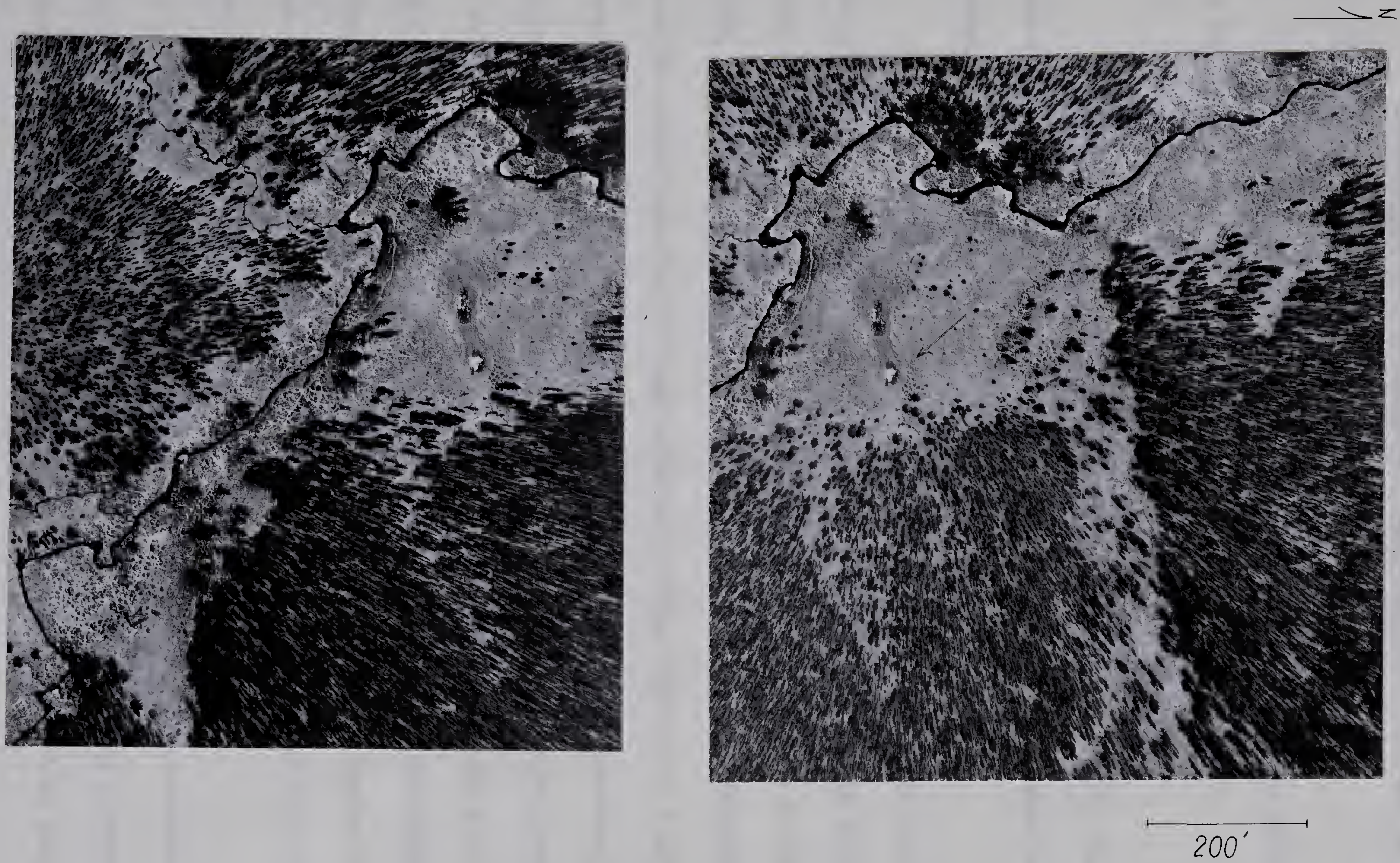


Plate 12. Groundwater discharge features Wampus Creek sub-basin.

Depending on weather conditions, these areas are either zones of vegetal discharge or groundwater seepage.

Plate 11 gives a visual impression of hummocky ground. The dark area in the top-center part of the photograph is a seepage.

Description of three specific discharge areas

Wampus Creek sub-basin: (discharge features 60, 61, and 62): The area chosen for description is a spring of the soaphole type located in the upper part of Wampus Creek sub-basin.

A map, made from an air photograph at the scale of one inch equals 200 feet (Fig. 12) shows the distribution of discharge features and tree types (see forest cover legend, Table 12). Plate 12 is a stereogram of the mapped area on the same scale. Plate 10 is a photograph of the area. Perusal of the map and stereogram shows the outward gradation of the groundwater discharge features from a spring of the soaphole type in the center to a seepage area, and finally to hummocky ground at the margin. This gradation shows as a tonal change in the stereogram because of differing reflective properties of vegetation. The dark-toned center part of this type of spring is open water and decayed vegetation. The medium tone of grey, mapped as groundwater seepage, indicates the presence of sedge. Swamp birch and willow are the dominant plant types growing on the area mapped as hummocky ground.

The stereogram also shows quite clearly the terrace effect mentioned in the geomorphology section of this report. The photograph (Plate 10) provides a closer view of this phenomenon and also the previously cited vegetation change from sedge to swamp birch.

Many game trails can be clearly observed in the stereograms (Plates 12 and 13). It is probable that the hummocky surface of the ground is caused in part by tramping of big game animals.

The interpretation of the groundwater flow system which produces the Wampus Creek discharge area is illustrated in figures 13, 14, and 15.

The area is located on the east flank of the Brazeau syncline. Beds of the Brazeau Formation strike N70°W and dip 50°SW (Fig. 13). The bedrock at the discharge area is mantled with less than ten feet of local till.

Field observations suggest that the flow of groundwater to this area follows the bedding planes and fracture system of the lower Brazeau Formation. These observations are:

a) The outcrop of the lower Brazeau Formation on the crest of the ridge above the discharge area exhibits cracks two inches wide along the bedding planes. These cracks are open to a depth of at least four to five feet. The cracks control infiltration of precipitation.

b) The beds dip directly downslope toward the discharge area.

c) The rocks of the lower Brazeau Formation exposed in the road cut (Plate 2) show slight wetness along the bedding planes. The moisture is also found along the joints and is concentrated at the junction of the bedding planes and joints.

The structure cross section (Fig. 13) shows a two-dimensional view of the interpretation.

A three-dimensional interpretation of the conditions present is shown in figures 14 and 15.

Recharge of groundwater to the system occurs at the crest of, and on the

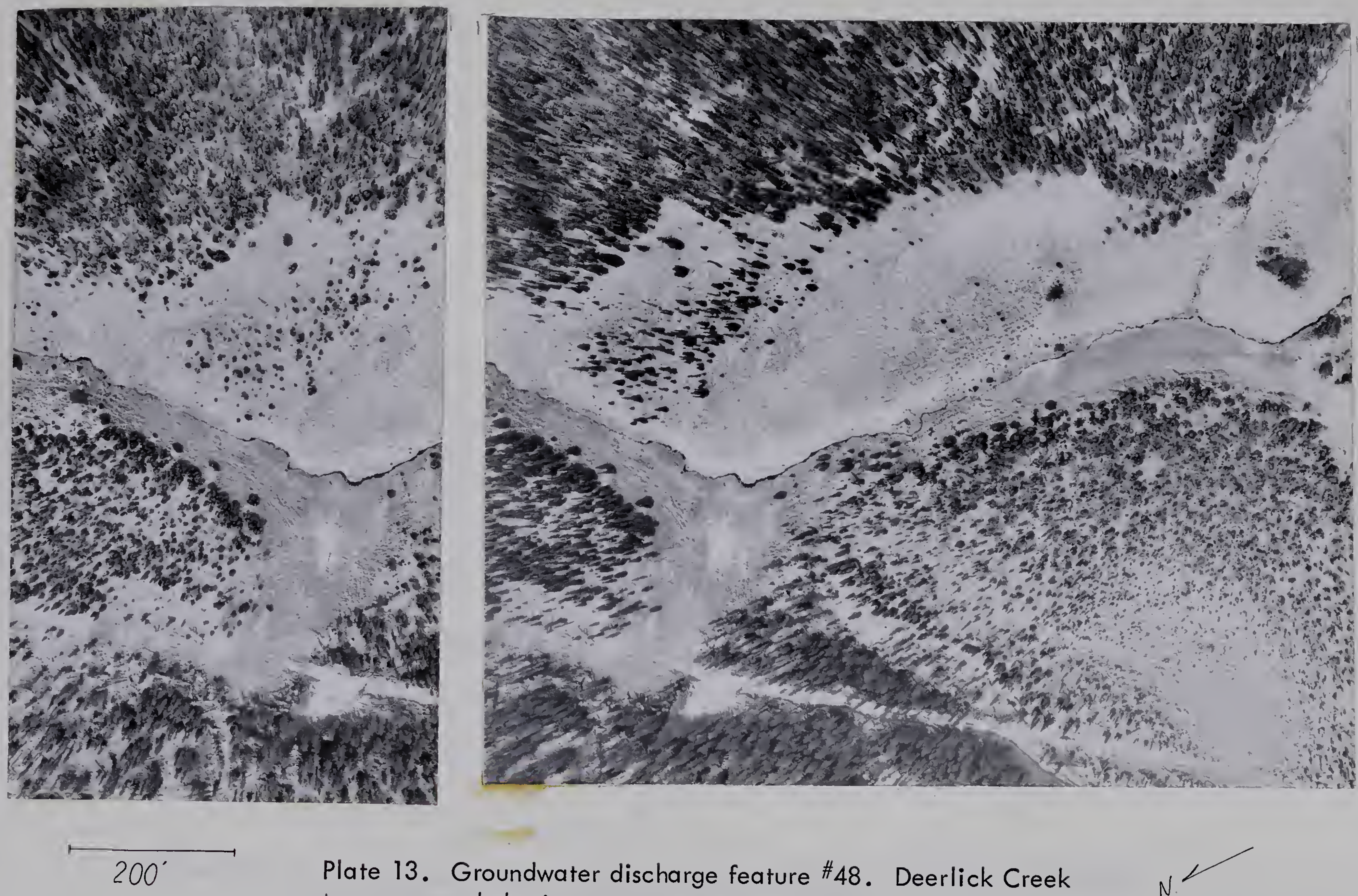


Plate 13. Groundwater discharge feature #48. Deerlick Creek sub-basin.

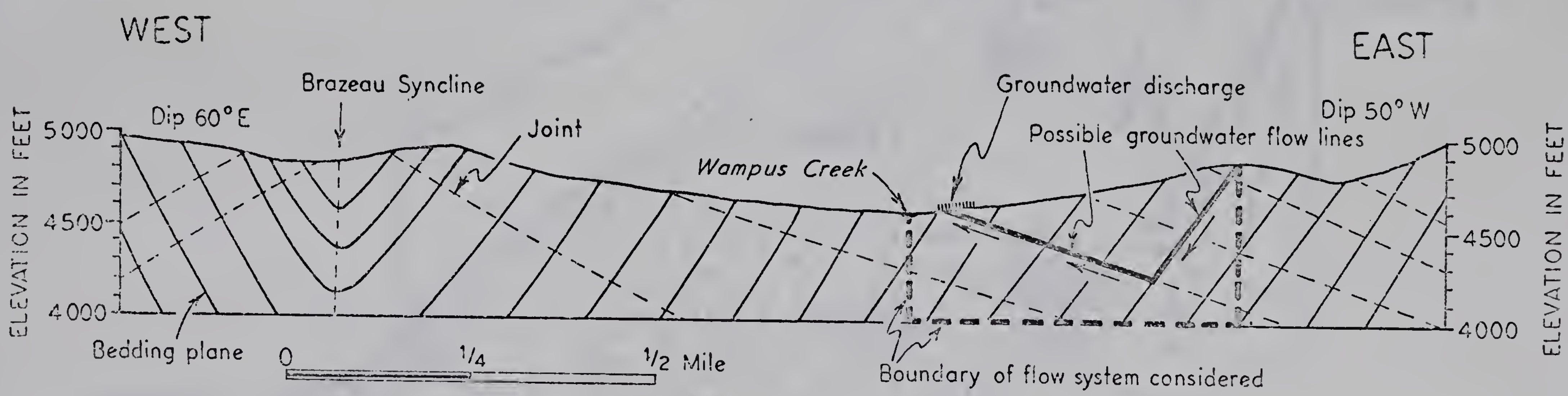


Figure 13. Structure cross section, Wampus Creek sub-basin, showing relationship of groundwater flow to bedding planes and joints

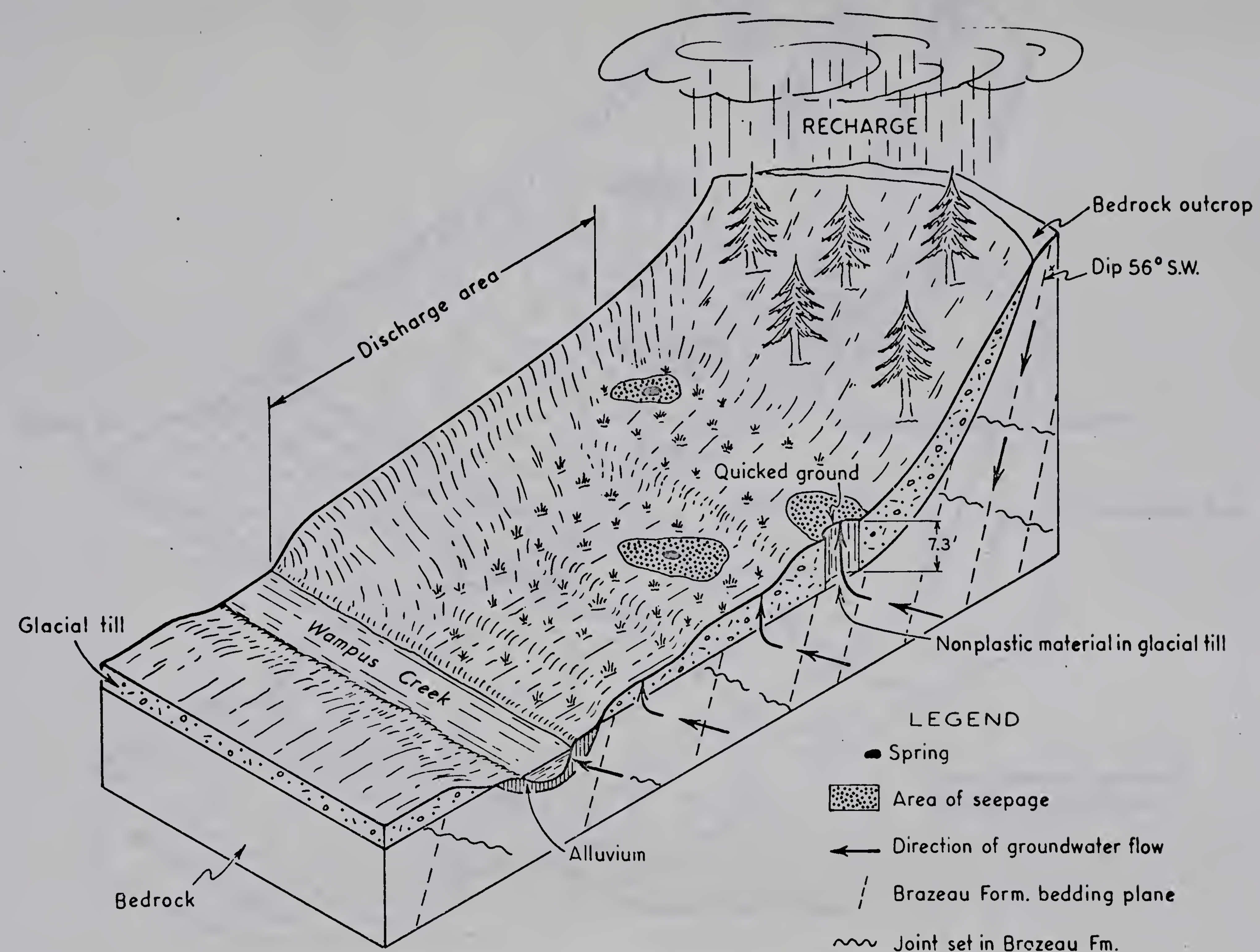


Figure 14. Block diagram of Wampus Creek discharge features numbers 60 and 61

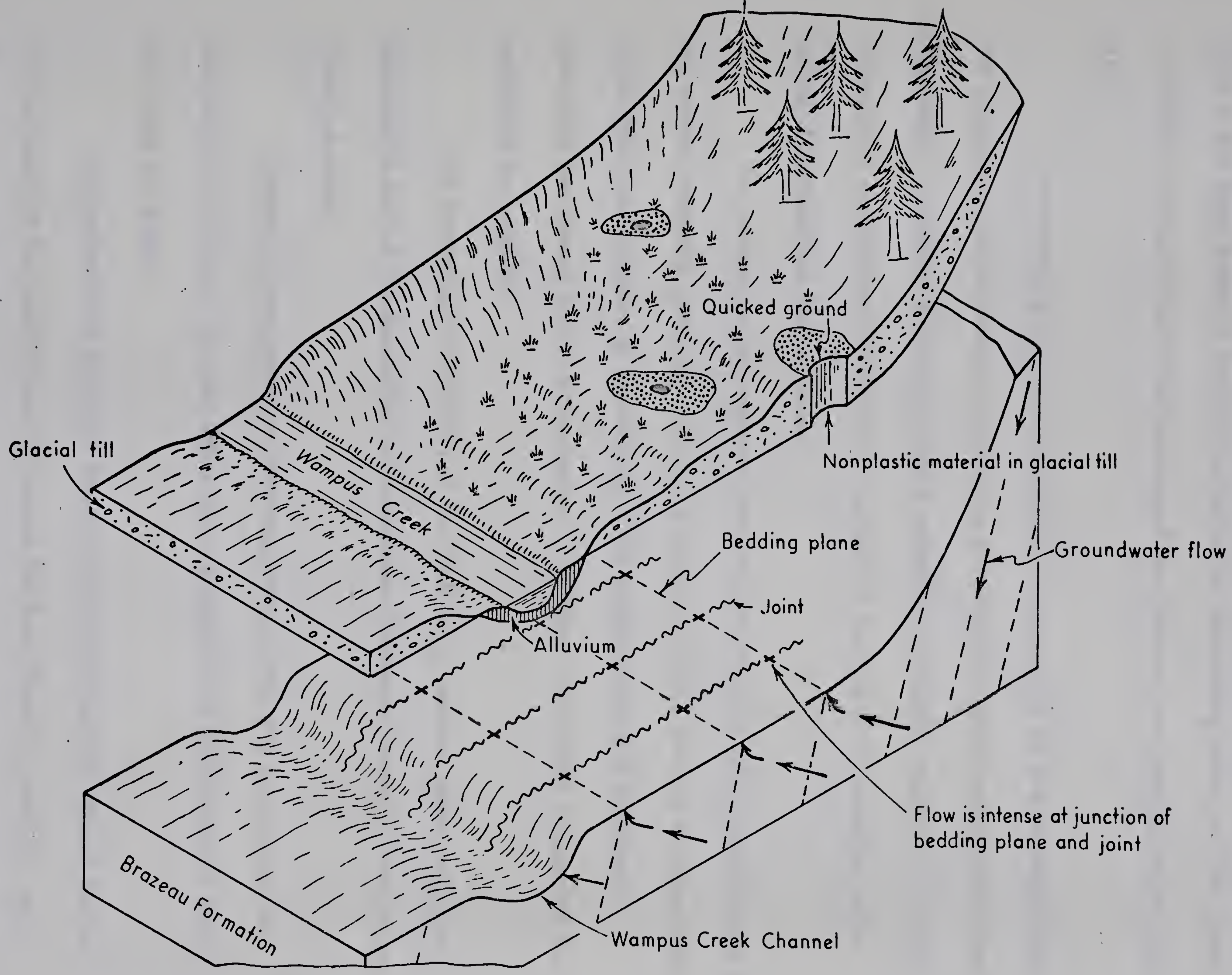


Figure 15. Block diagram of Wampus Creek discharge features numbers 60 and 61 — till sheet raised

pine covered slope of the lower Brazeau Formation ridge (Fig. 14). The groundwater flow in this local system is strongly controlled by the bedding planes and the joints. The flow is concentrated at the junctions of the joints and the bedding planes (Fig. 15).

The overlying blanket of glacial till is assumed to be less permeable than the underlying jointed bedrock, and acts as a deterrent to upward groundwater flow. The water, in order to discharge, seeks a pocket of non-plastic material. The high intensity of groundwater flow quicks the ground in the area of this material and a spring of the soaphole type is formed.

The intensity of groundwater flow required to cause quick ground occurs at the critical hydraulic gradient. Under this condition of flow there is no stress transmitted from grain to grain in the material. The weight of the soil particles is carried by the upward flow of groundwater. Therefore, no shearing stresses can be carried by the material.

An analysis of the velocity of flow needed to create a quick condition is presented as part of the description of groundwater discharge features in the Eunice Creek sub-basin.

Deerlick Creek sub-basin (discharge feature 48): The area chosen for description is a spring of the rock debris type, located in the central part of Deerlick Creek sub-basin.

The groundwater discharge features and forest cover are mapped from an air photograph at the scale of one inch equals 200 feet (Plate 13, and Fig. 16). Plate 6 is a photograph of the meadow associated with the groundwater discharge.

The discharge area differs from the one previously described in that:

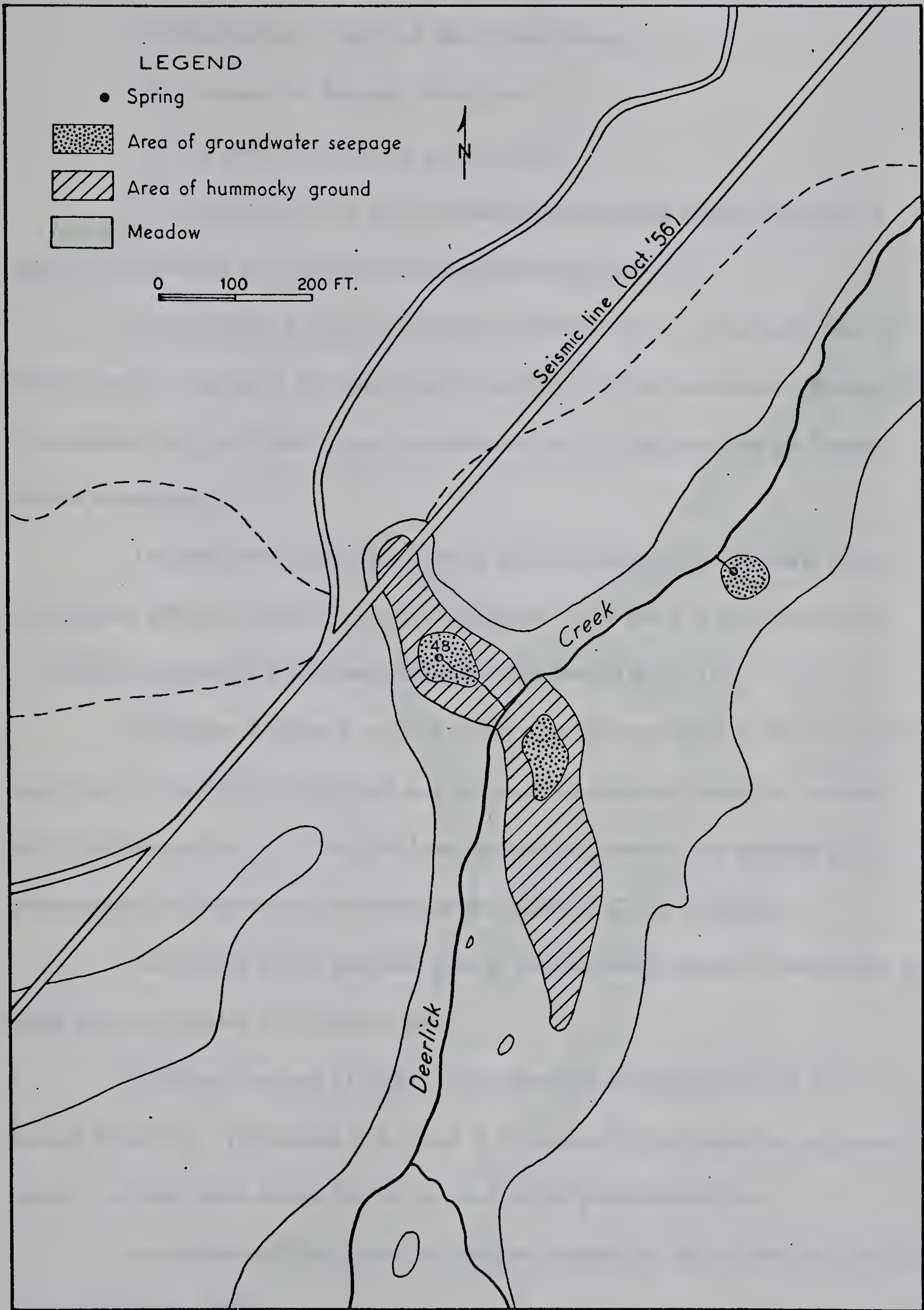


Figure 16. Groundwater discharge features, Deerlick Creek sub-basin

a) The bedrock is shale of the Alberta Group.

b) It is near the Brazeau thrust fault.

c) The ground around the spring is firm.

The interpretation of the groundwater flow system into this meadow is given in the section on hypothetical groundwater flow patterns.

Eunice Creek sub-basin (discharge features 1 to 6, inclusive): This discharge area is located in the upper part of the Eunice Creek sub-basin. Springs of the soaphole and rock debris types are observed, as is a larger discharge feature termed a seepage pit.

The area was mapped partly from an air photograph at the scale of one inch equals 200 feet, partly from air photographs at the scale of one inch equals 1,000 feet, and partly from measurements on the ground (Fig. 17).

Discharge features 1 to 6 are located on the west flank of the Tri-Creek syncline. The bedrock is sandstone and shale of the Brazeau Formation, mantled with glaciolacustrine silt. The silts have slumped adjacent to the seepage pit, a phenomenon not observed at the Wampus and Deerlick Creek locations.

The springs of the soaphole type at this discharge area are comparable to those found elsewhere in Tri-Creek basin.

Discharge feature #1 (Fig. 17) is expressed topographically as a low mound (Plate 14). This mound is inferred to be caused by the upwelling of groundwater. An area of 64 square feet is quicked by the groundwater flow.

An estimate of the hydraulic gradient required to quick glaciolacustrine silt is (Rutledge, 1940):

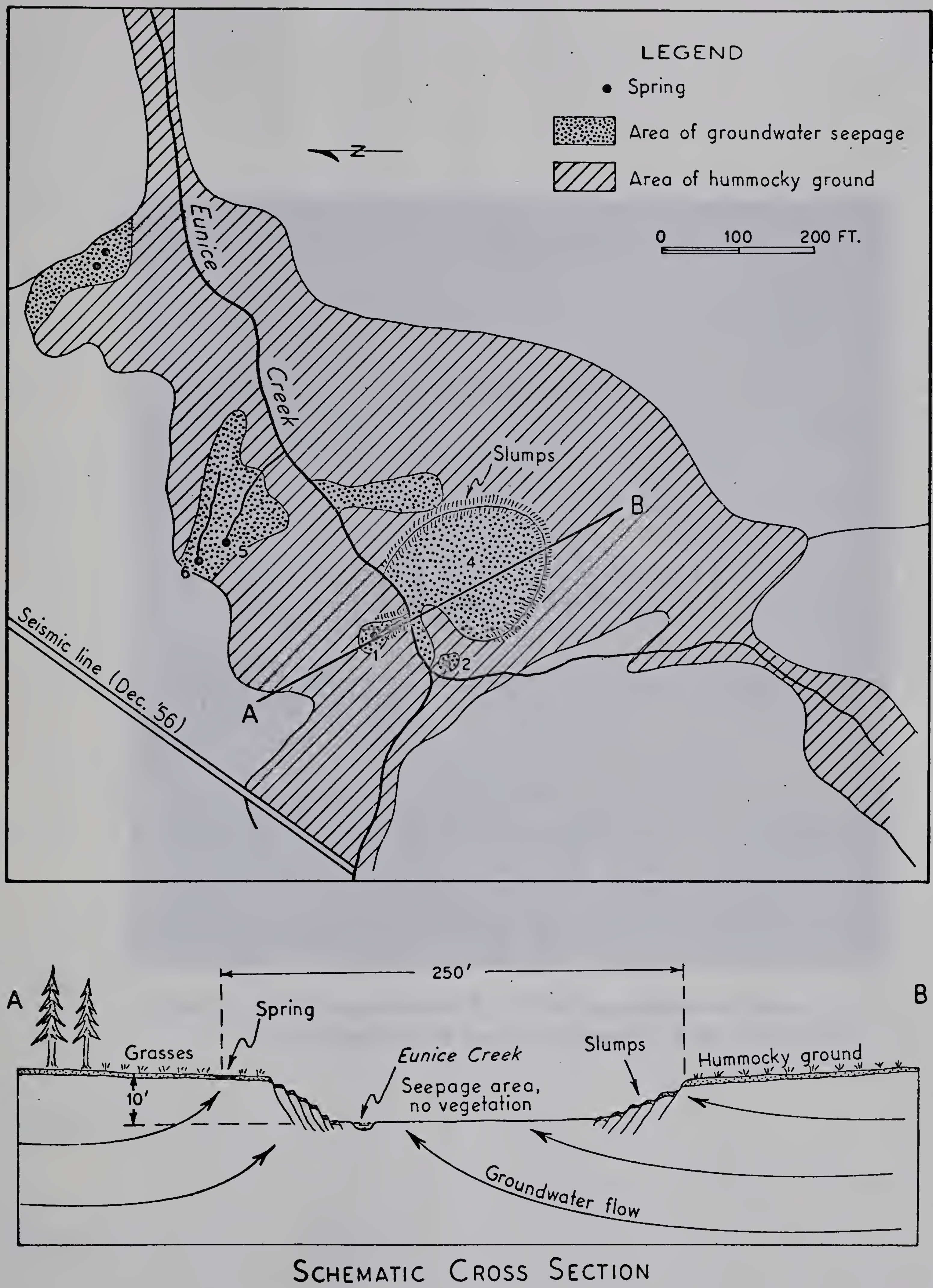


Figure 17. Groundwater discharge features, Eunice Creek

Plate 14. Discharge feature #1. The vegetation mat forms a circular mound nine feet in diameter and six inches high.

$$i_c = \frac{Gs - 1}{1 + e} \qquad (2)$$

$$= \frac{2.70 - 1}{1 + 1} = .85$$

where i_c = critical hydraulic gradient

G_s = specific gravity of soil solids (assumed value of 2.70)

e = void ratio (defined as volume of the voids divided by volume of soil solids; value of e = 1 estimated)

The value of .85 for the critical hydraulic gradient can be used to calculate a seepage velocity:

$$V_d = Ki_c \qquad (3)$$

$$= 1 \times 10^{-5} \times .85 = 8.5 \times 10^{-6} \text{ cm/sec}$$

and

$$V_s = Vd \frac{1 + e}{e} \qquad (4)$$

$$= 8.5 \times 10^{-6} \times \frac{1 + 1}{1} = 1.7 \times 10^{-5} \text{ cm/sec}$$

where Vd = velocity discharge

K = permeability

V_s = seepage velocity.

A range of permeability for mixtures of sand, silt, and clay, glacial tills, etc., given by Means and Parcher (1963) is from 10^{-3} to 10^{-7} cm/sec. The mean value of 10^{-5} cm/sec is used in the preceding calculations.

The flow necessary to cause quick conditions over an area of 64 square feet can be calculated from Darcy's Law:

$$Q = KiAt \qquad (5)$$

and

$$q = \frac{Q}{t} = KiA \qquad (6)$$

where Q = total quantity of water flowing through a soil having a total area A, in time t, under hydraulic gradient i. K is a coefficient of permeability.

q = quantity of flow per unit time.

$$q = KiA$$
$$= (1 \times 10^{-5} \text{ cm/sec}) \cdot (59{,}458 \text{ cm}^2) \cdot (.85)$$
$$= .5054 \text{ cm}^3/\text{sec} \quad [.0067 \text{ igpm}]$$

The quantity of flow measured in the channel leading from discharge feature #1 on May 26, 1967 was 1.5 igpm (113.5 cm^3/sec). This quantity of flow could quick an area of:

$$A = \frac{q}{Ki_c} \tag{7}$$
$$= \frac{113.5 \text{ cm}^3/\text{sec}}{8.5 \times 10^{-6} \text{ cm/sec}}$$
$$= 13 \times 10^6 \text{ cm}^2 \quad (14{,}000 \text{ sq ft})$$

The calculations indicate that a flow of 1.5 igpm is more than sufficient to quick the materials underlying all the groundwater discharge features in Tri-Creek basin except the seepage pit which has an area of 16,800 square feet.

A flow of 10 igpm is estimated for the seepage pit. This volume of flow is variable and diffuse but would be more than sufficient to quick the area concerned.

The values for specific gravity, void ratio, and coefficient of permeability were obtained from Means and Parcher and are the best available at this time.

A smaller spring of the soaphole type (discharge feature 2, Fig. 17) is located across Eunice Creek from feature #1 and is 12 square feet in area (Plate 15). The rate of discharge from this smaller spring is estimated at less than one half gallon

Plate 15. Discharge feature #2. The dark stick in the background marks the location of discharge feature #1 (Plate 14) Eunice Creek sub-basin.

per minute (Table 10). The water flowing to Eunice Creek has cut a channel one to two feet deep. Slumps occur along this channel creating an arcuate, bowl-shaped depression, concave toward the junction with Eunice Creek. The same conditions are observed at the much larger feature across the creek (Plate 14).

Field evidence indicates that the slump process may be one agent in the enlargement of the discharge features (Plate 16).

The seepage pit is a large (120' x 140'), nearly circular depression, the edges of which have slumped. The floor of the pit is very wet and soft underfoot. Discharge of groundwater is diffuse. On one traverse, one part of the pit floor was covered with mud boils (Plate 17). One week later the mud boils were located elsewhere on the pit floor.

Groundwater discharge is estimated to be about ten gallons per minute from the seepage pit. The day-to-day variation in the location of springs and seepages on the floor of the pit made discharge difficult to estimate. In spite of this difficulty, the impression gained was that the groundwater discharge increases in response to wet weather.

Conductivity Survey

The results of a conductivity survey carried out in mid-July, 1968 (Table 15) indicate that the groundwater discharging in Tri-Creek basin is low in dissolved solids. The conductivity ranges from less than 50 to 425 micromhos per centimeter (conductivity micromhos x .7 = ppm, Davis and DeWiest, 1966).

The amount of total dissolved solids in the groundwater is proportional to the length of the groundwater flow path (Chebotarev, pt. 2, p. 144, 1955).

The low total dissolved solids content of the groundwater discharging in

Plate 16. Seepage pit. Eunice Creek flows to the left at mid-photo. Note slump at back wall. Discharge feature #4.

Plate 17. Small mud boil on floor of seepage pit (Plate 16). Discharge feature #4.

TABLE 15.

CONDUCTIVITY SURVEY RESULTS

* Stream measurements ● "Soap hole" discharge

STA. NO.	TEMP °F	CONDUCTIVITY (m mhos/cm)	LOCATION & REMARKS
1	54	160	Eunice Creek medium size spring ●
2	40	280	Eunice Creek small size spring ●
* 3	44	108	East tributary above pit
4	38	215	Northside seepage
5	40	400	Spring that enters creek
6	50	420	Spring the doesn't enter creek ●
7	54	95	Pond next tributary east of pit
8	35	125	Spring at rear of pond clearing ●
9	42	75	Spring south of earth flow ●
10	45	75	Spring in clearing 2000' south of Eunice Pit ●
11	-	-	Spring on tributary to Eunice Pit ●
12	39	50	Spring at sharp bend in 16 road ●
13	48	90	Seepage just before Eunice Divide
14	50	200	Seepage at Eunice Divide
15	44	200	Seepage at Eunice Divide
16	67	160	Roadside seepage at Wind Gap on Trapper Ck.
17	36	425	Spring in Wind Gap on Trapper Road ●
18	55	80	Ponded water in amphitheatre
19	58	140	Mossy seep, hole dug, 5100' elev.
*20	42	220	Stream measurement
21	-	-	Mossy seep
22	-	-	Dry terrace - seep in past
23	44	95	Spring - with rock debris

CONDUCTIVITY SURVEY

RESULTS

* Stream measurements

● "Soap hole" discharge

STA. NO.	TEMP °F	CONDUCTIVITY (m mhos/cm)	LOCATION & REMARKS
*24	48	180	Stream measurement
*25	48	210	East tributary
*26	50	150	West tributary
*27	50	190	Main stream
28	38	180	Spring - active bubbles 3 gpm 4' x 3' x 6"
*29	48	215	Just above cut line
30	-	-	Bubbles on seismic line ●
*31	45	135	Cut line crosses creek
32	40	150	Terrace seepage
33	39	140	Terrace seepage
34	41	50	Wapiabi seepage near Wampus "C"
*35	57	140	In creek at Cardium outcrop
36	52	150	Water table well at #3
37	72	50	Seepage at sharp bend Craig's Road
*38	55	160	At Wampus main weir
39	37	142	Spring with rock debris below Deerlick high road
40	37	250	Spring near confluence 3' x 4' x 3 1/2'
41	-	-	Spring near confluence 4' x 5' x 3 1/2'
*42	43	180	Upstream of discharge features 40 + 41
*43	42	163	Downstream of discharge features 40 + 41
44	37	158	Spring 5 gpm - rock debris type
45	-	-	Amphitheatre broad leaves
46	-	-	Fan ? channelled - possible slide

CONDUCTIVITY SURVEY

RESULTS

* Stream measurements

● "Soap hole" discharge

STA. NO.	TEMP °F	CONDUCTIVITY (m mhos/cm)	LOCATION & REMARKS
*47	44	220	South end of grassy meadow
48	65	100	Deerlick spring
49	37	155	Cross basin road in Deerlick 1/2 gpm
*50	47	70	Tributary to Deerlick at road
*51	50	161	Main Deerlick stream at road
52	47	90	Spring with rock debris
53	37	130	Spring with rock debris
*54	50	158	Meander pool
*55	50	160	Cut line - road junction
56		96	Near #4 well site
57		180	Mossy seepage near creek ●
58		100	Mossy seepage ●
59		118	Spring above first find 4 x 4 ●
60		105	Spring at first find (rear) 10' x 10' x 5.2' ●
61		110	Spring at first find (middle) 12' x 12' x 7.3' ●
62		100	Spring at first find (little one) 3' x 3' x 4.2' ●
*63		167	Main stream Wampus Creek
*64		100	South tributary to Wampus Creek
65		200	Dry up spring
*66		110	Barnyard stream
67		200	Wavy ground spring ●
68		85	Spring at Barnyard
69	65	60	Ponded water near Wampus "C"
*70	48	165	Wampus Creek at pond 69
*71	48	65	Cardium tributary to Wampus

CONDUCTIVITY SURVEY

RESULTS

* Stream measurement ● "Soap hole" discharge

STA. NO.	TEMP °F	CONDUCTIVITY (m mhos/cm)	LOCATION & REMARKS
72	36	70	Spring-rock debris with mossy bog
*73	46	55	East pond tributary
*74	55	150	At the outcrop near Seabolt Axis
*75	57	162	Low cut line crosses Wampus Ck.
76	65	110	Seepage on cut line above Deerlick Ck.
*77	54	162	Cut line crosses Deerlick Creek
78			Erratic of L. Cambrian 6' x 4' x 3'
*79	44	220	Tributary to Eunice Ck. above clearing
*80	46	209	Main stream Eunice Ck. at clearing
*81	53	200	Eunice Creek weir
*82	57	165	Deerlick Creek weir
*83	52	135	Trapper Creek at McLeod River
*84	59	240	McLeod River at foot of basin
*85	50	62	West tributary to Wampus Creek at "C"
*86	55	295	McLeod River at Craig's Bridge
*87	56	298	McLeod River at 16 campground
*88	48	120	Culvert on Eunice Ck. road
*89	46	65	Wampus Ck. tributary N.W. portion of basin
90	39	118	Millsite on Wampus spring
91	49	70	Millsite bank spring
92	53	155	Wampus Ck. at millsite
93	41	280	Leyland Mtn. spring 10 miles from basin
94	47	260	Whitehorse river at campground

the basin indicates that the groundwater flow systems are short.

No pattern to the conductivity values was established (Map 5, in pocket).

The highest specific conductance measured is in a spring of the soaphole type (sta. 17) located in the bottom of a meltwater channel cut through the basin divide. The position of this spring indicates that it should be reasonable to assume a local flow system. The conductivity value indicates a longer flow path.

Water samples from this and other springs were sent for analysis during June 1968. Interpretation of the relationship between the anomalous conductivity value and the geographical location of station 17 is deferred pending results of the analyses.

Hypothetical Groundwater Flow Patterns

The flow patterns (Figs. 18 and 19) are schematic, and superimposed on a structure cross section drawn along the axis of Wampus Creek groundwater basin. The flow patterns are drawn to illustrate the probable effects of geological non-homogeneity on groundwater flow. A groundwater basin is a three-dimensional closed system that contains the entire flow paths followed by all the water recharging the basin (Freeze and Witherspoon, 1967).

The boundaries of the groundwater basin are:

a) The water table, which is assumed to approximate the topographic surface.

b) An assumed impermeable base at sea level. This elevation is arbitrarily chosen as a point of departure for discussion. The choice of another elevation would change the depth but not the distribution of groundwater flow (Tóth, 1962a).

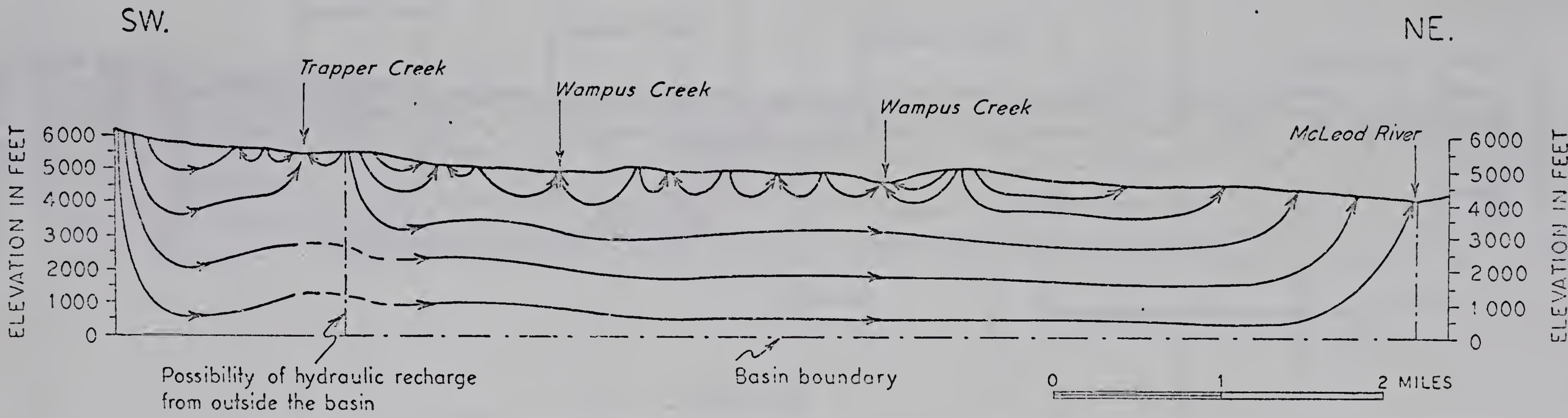


Figure 18. Hypothetical groundwater flow pattern — homogeneous and isotropic conditions

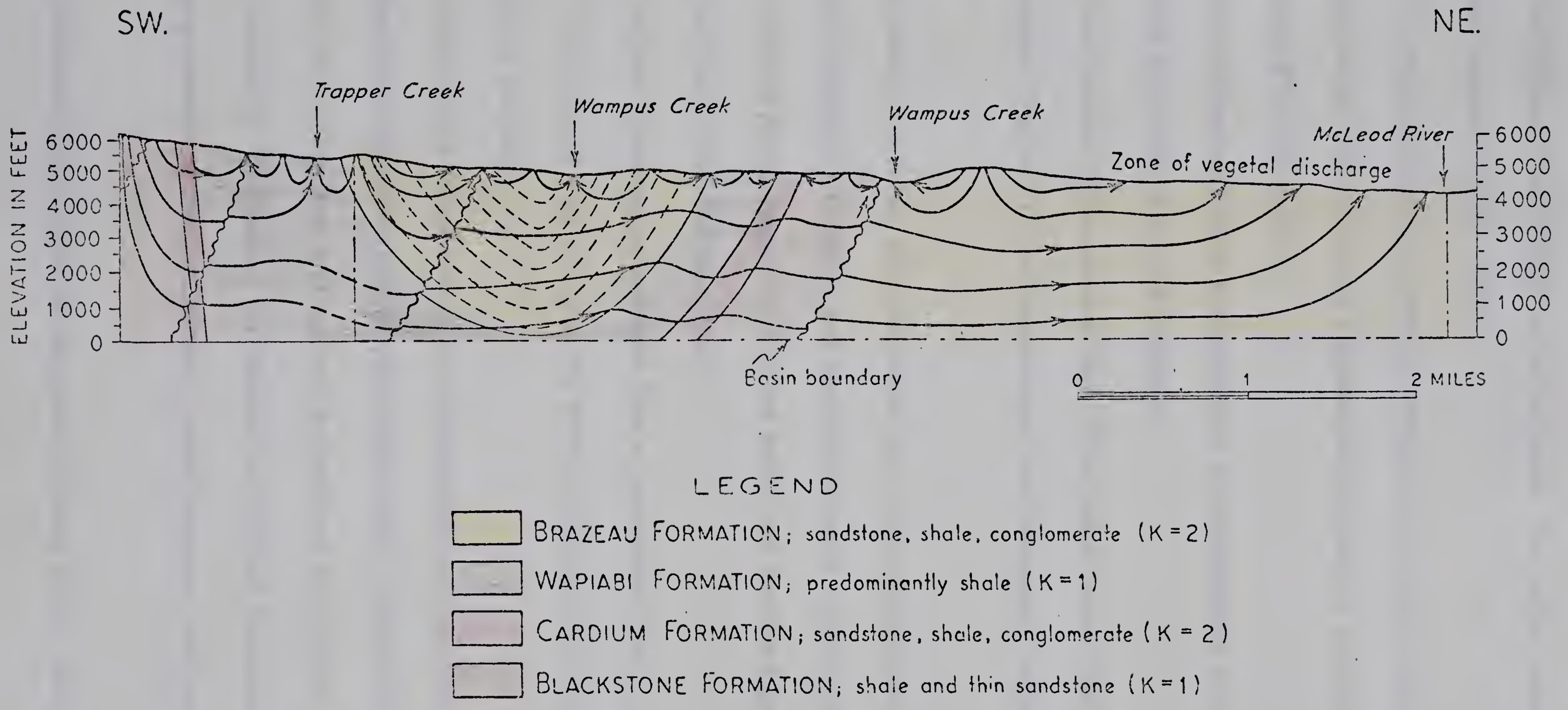


Figure 19. Hypothetical groundwater flow pattern — fault zones considered more permeable than the faulted bedrock

c) The McLeod River valley to the northeast. The valley forms a theoretical impermeable boundary (Toth, 1962b).

d) The topographic divide between Wampus and Trapper Creeks. Subsurface recharge through this theoretical impermeable boundary is considered possible at lower elevations (Figs. 18 and 19).

Three terms necessary to the discussion of the hypothetical groundwater flow patterns have been defined by Toth (1962a):

1) Local system of groundwater flow - This type of system has its recharge area at a topographic high and its discharge area at the immediately adjacent topographic low.

2) Intermediate system of groundwater flow - The chief characteristic of this system is that although its recharge and discharge areas do not occupy the highest and lowest elevated places respectively in the basin, one or more topographic highs and lows may be located between them.

3) Regional system of groundwater flow - groundwater flow is considered to be regional if its recharge area occupies the water divide and its discharge area lies at the bottom of the basin.

The location and description of the discharge features associated with local flow systems have constituted a large part of this report. The local systems are superposed on the intermediate and regional groundwater flow systems (Fig. 18).

For purposes of illustration, the Brazeau and Cardium Formations are considered twice as permeable as the predominantly shale Blackstone and Wapiabi Formations.

Groundwater flow is deflected downward at zones of low, and upward

at zones of high permeability (Fig. 19).

The assumed greater permeability of the fault zones and the Brazeau and Cardium Formations tends to provide the intermediate and regional groundwater flow systems with an upward component of flow not present in the homogeneous and isotropic case. This upward component and the assumed greater permeability of the fault zones may result in the discharge of groundwater along the fault traces.

Air photograph and field observations indicate that the Brazeau fault zone may be more permeable than the faulted bedrock. These observations are:

1) Major groundwater discharge features are observed near the fault zone in Wampus and Deerlick sub-basins (Fig. 11 and Plate 13).

2) The upper portion of Deerlick sub-basin adjacent to the fault zone is covered by meadow vegetation.

Subsurface recharge to the groundwater basin from the high ridge southwest of the Tri-Creek basin boundary is considered possible. The presence of the broad zone of vegetal discharge (Fig. 19), which consists of the northern quarter of the basin lends support to this hypothesis. Quantitative measurements are not yet available either as to the amount of groundwater flowing into the discharge area or as to the amount of water transpired by the vegetation in the basin. This lack of knowledge precludes further evaluation of the possibility of deep groundwater flow into the discharge area.

Instrumentation

General Statement

The instrumentation placed in Tri-Creek basin by the various co-operating agencies is shown on map 4 (following p. 89).

The groundwater instrumentation is not complete. To date it consists of four piezometer nests and four water table wells, all located in the Wampus Creek sub-basin.

Water levels in the piezometers and water table wells installed during the autumn of 1967 are measured each week with a chalked steel tape. Hydrographs are being constructed, but are not included in this report.

Consideration is being given to installation of three new piezometer nests, and to a pump test to establish hydraulic conductivity values.

Drilling

The drilling sites were located to provide ease of access, maximum stratigraphic information, and to permit definition of the geometry of the groundwater flow system.

The holes were bored by a truck-mounted rotary drill. The standard procedure was to drill and to collect samples of the surficial cover and then core to total depth. The sample and core descriptions of the material drilled are in appendix A.

Piezometers

The piezometers are one and one-half inch galvanized pipe, tipped with a slotted drive point. The points are located opposite water-bearing zones where-ever possible.

LEGEND

Canadian Research Basins, 1967

Drainage basin (key map only)

Contour (feet) — 700

Depression contour — 600

Basin boundary

Sub-basin boundary

Glacier boundary

Ice or snow boundary

Lake, pond, slough, wide river

Intermittent lake

Perennial stream

Intermittent stream

Spring

Sink

Swamp

Dam

Dyke

Road, all weather

Road, dry weather

Trail

Highway route marker — 25

Railway

Bridge

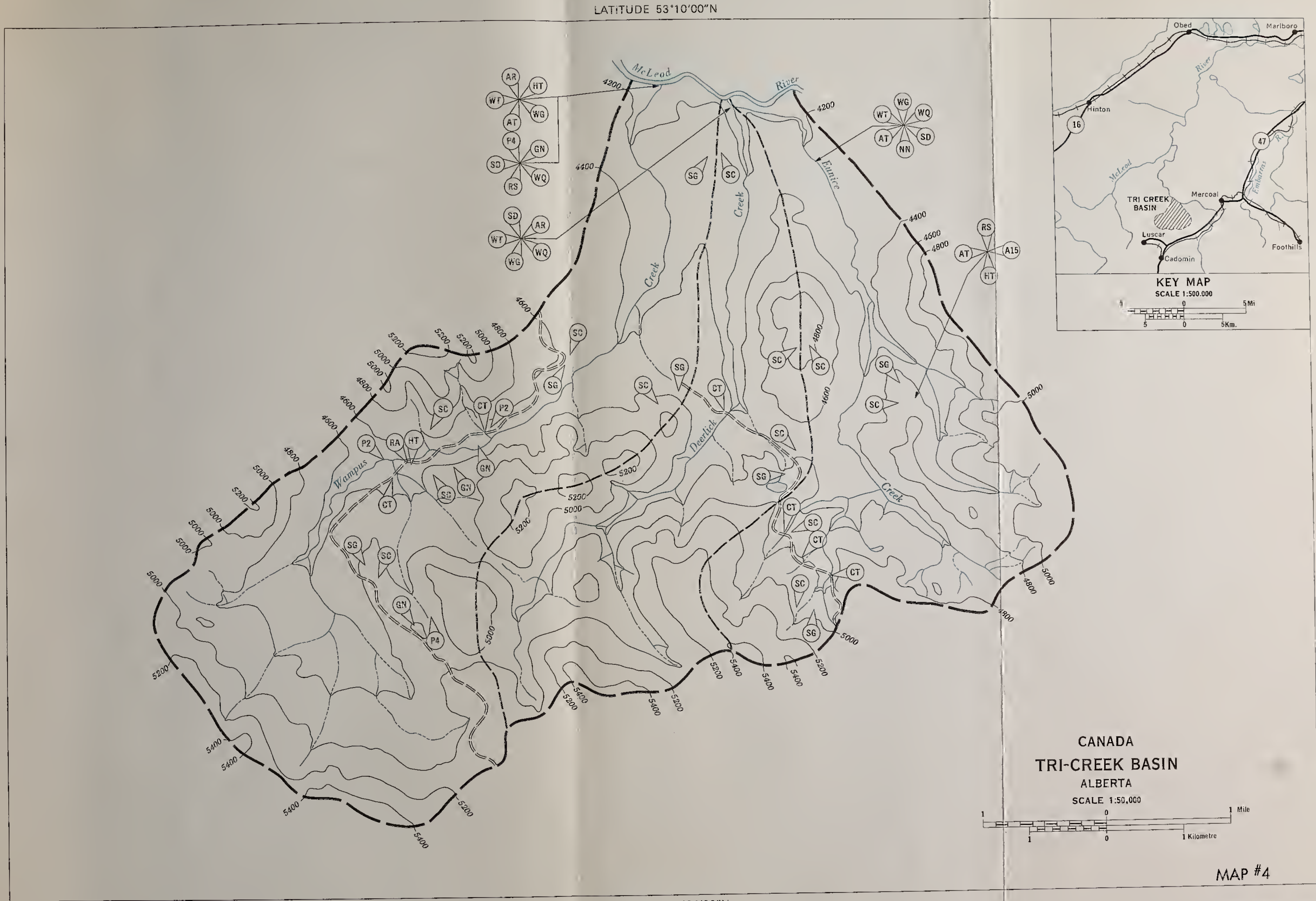
Culvert — CT

Bench mark — BM

Triangulation station

Cities, towns

Hydrometric station, natural control, recording	NR
Hydrometric station, natural control, non-recording	NN
Hydrometric station, artificial control, recording	AR
Hydrometric station, artificial control, non-recording	AN
Water level gauge	WG
Water temperature station	WT
Water quality station	WQ
Sedimentation station	SD
Groundwater well, recording	GR
Groundwater well, non-recording	GN
Piezometer (asterisk replaced by number of piezometers in nest)	P*
Snow course	SC
Snow gauge	SG
Snow stake	SS
Precipitation gauge, recording	PA
Precipitation gauge, non-recording	PN
Rain gauge, recording	RA
Rain gauge, standard	RS
Hygrothermograph	HT
Hygrometric station	HY
Anemometer (asterisk replaced by height above ground, in meters)	A*
Radiometer	SN
Sunshine recorder	SR
Evaporation station	ES
Soil moisture site	SM
Soil temperature site	ST
Tritium concentration in air	TC



Instrumentation Map

Bail Tests

The bail tests were conducted to obtain a value for the transmissibility of the penetrated sedimentary rocks. The coefficient of transmissibility is calculated according to the Jacob modification of the Theis nonequilibrium equation (Todd, 1959):

$$T = \frac{264Q}{\Delta s} \tag{8}$$

where T = transmissibility in igpd/ft

Q = bailing rate in ig/min

Δs = drawdown in feet/log cycle.

Transmissibility values of 136 and 176 igpd/ft were obtained for the Brazeau Formation at the Wampus Creek #1 site.

The Wapiabi Formation at the Wampus Creek #2 site is intensely fractured shale. The largest fragment observed in outcrop is a few inches in diameter. The bail test value of T at this site is 70 igpd/ft.

The lithologic logs and bail test data indicate that a range of values of transmissibility can be expected in the Brazeau Formation. The low value obtained from the Wapiabi Formation should be representative of the lithologic unit tested.

The relative values of transmissibility obtained for the Wapiabi and Brazeau Formations are comparable to those assumed in the hypothetical groundwater flow patterns (Figs. 18 and 19).

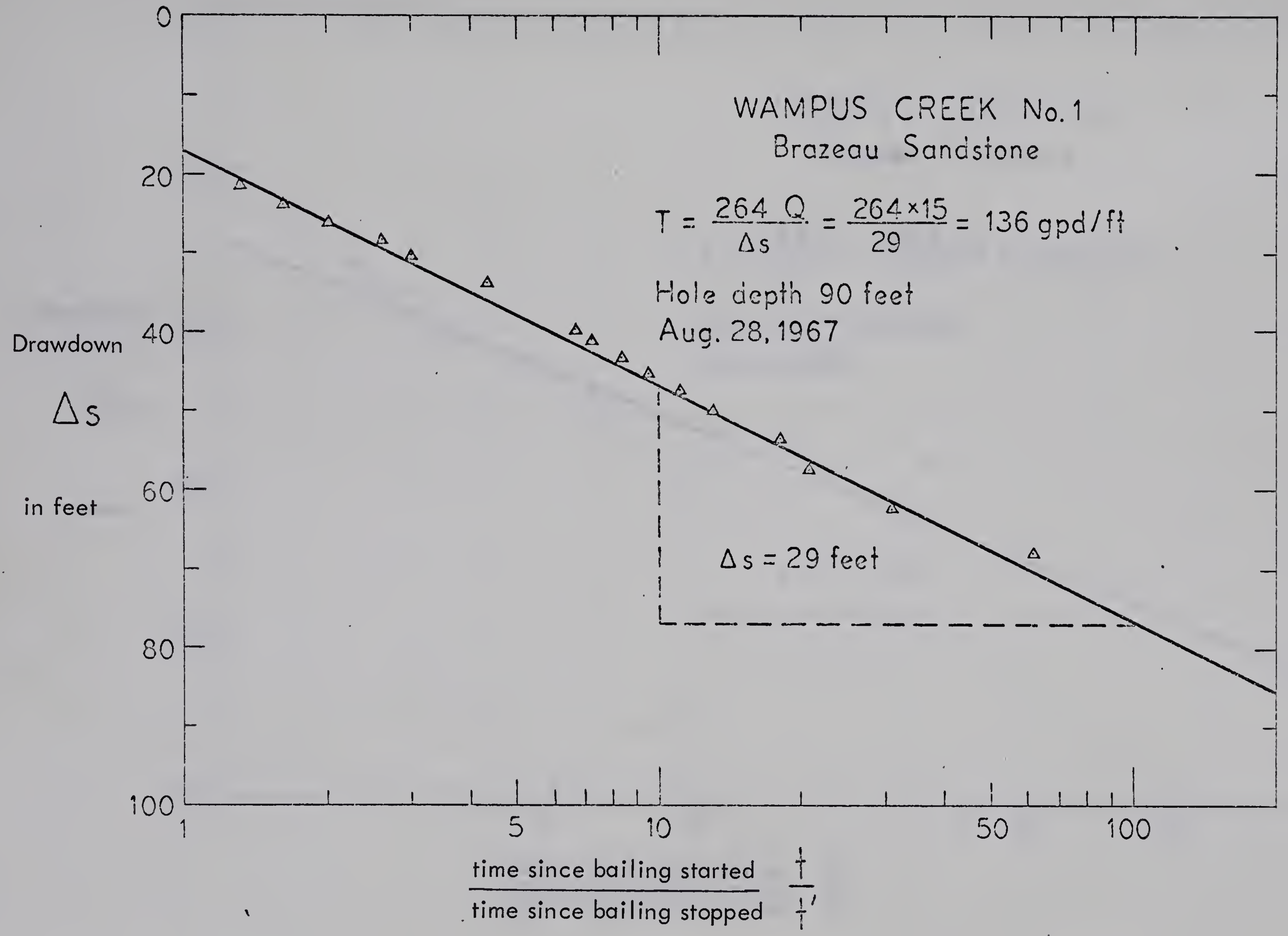


Figure 20. Bail test – Wampus Creek No. 1

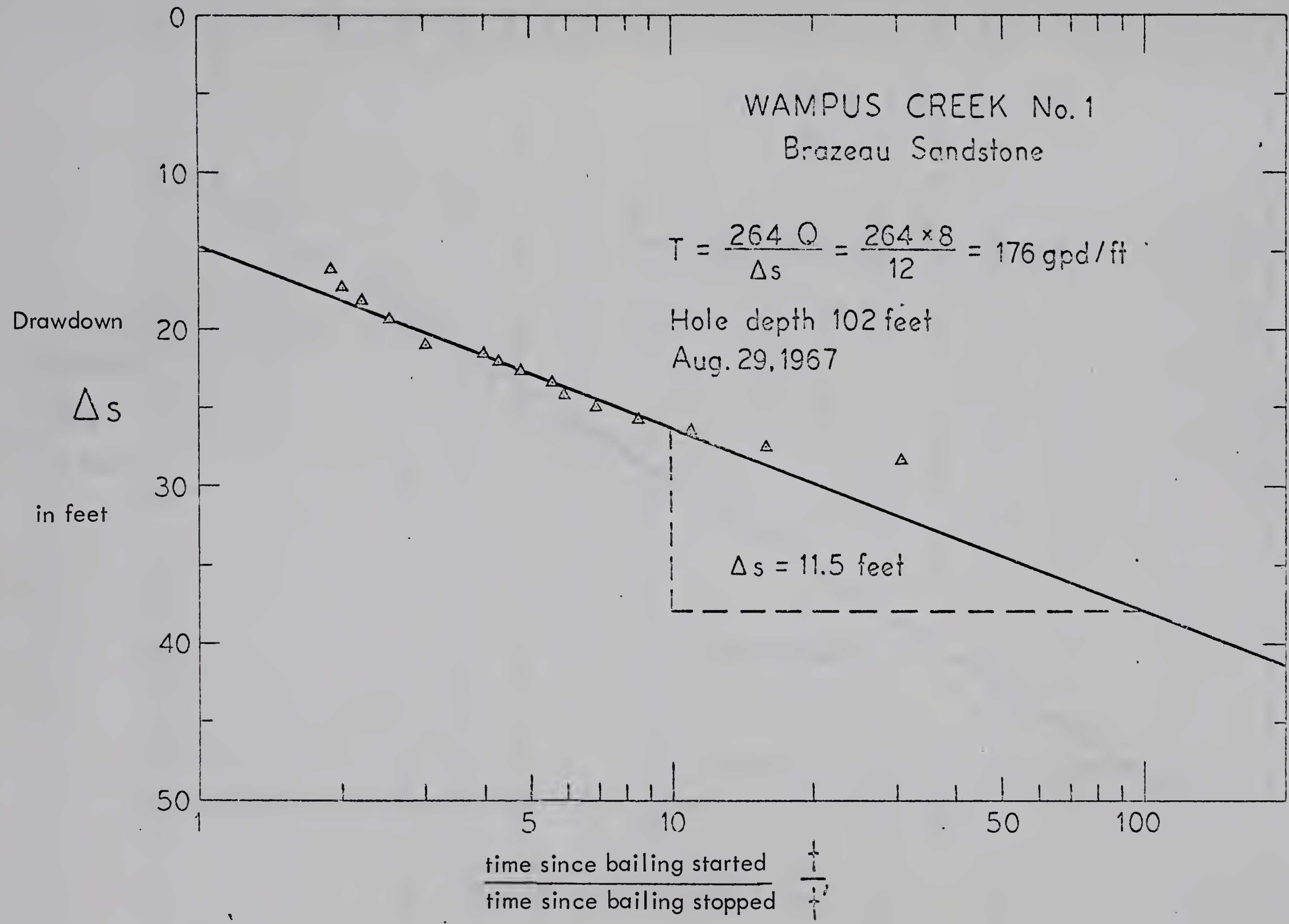
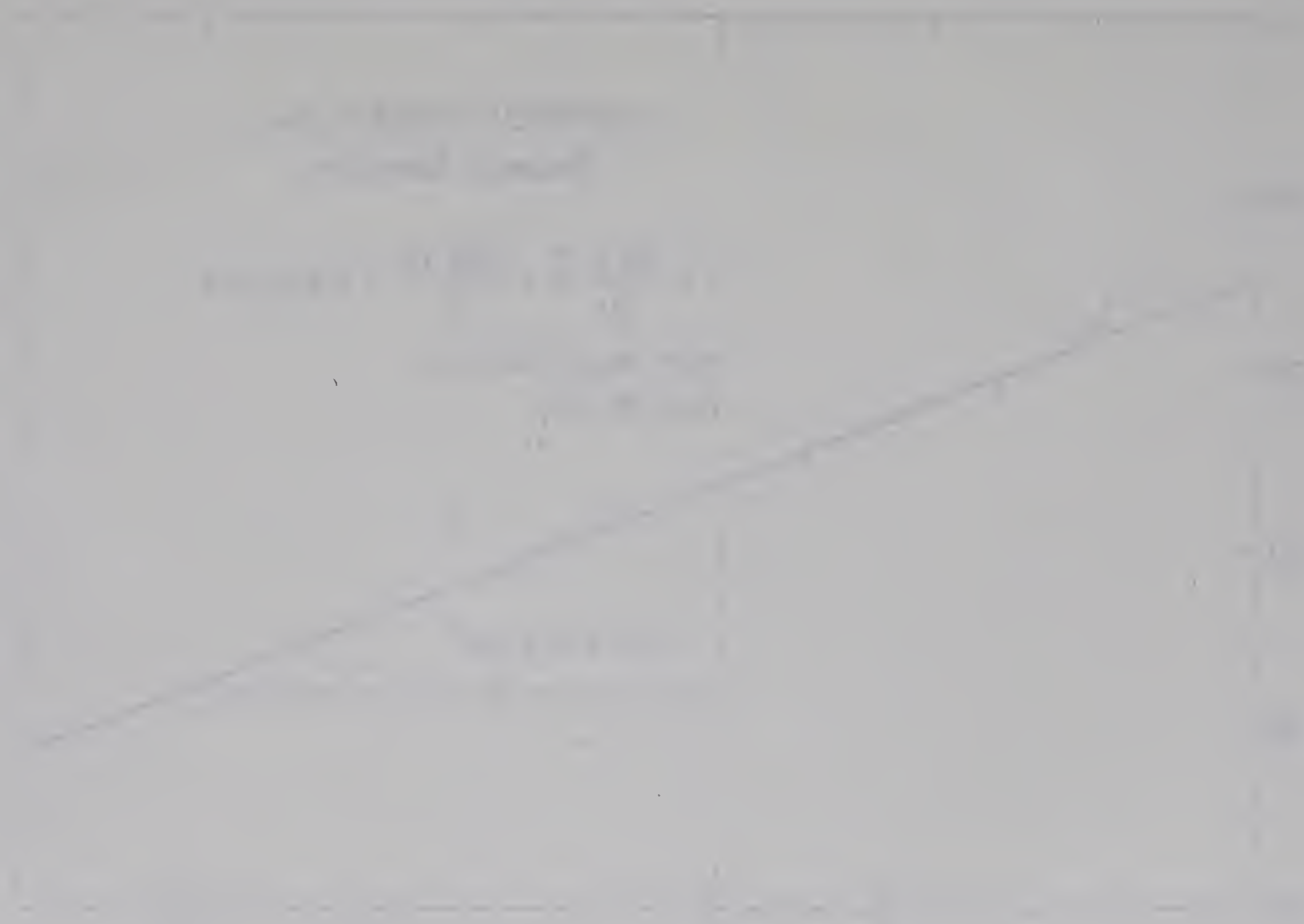


Figure 21. Bail test - Wampus Creek No. 1



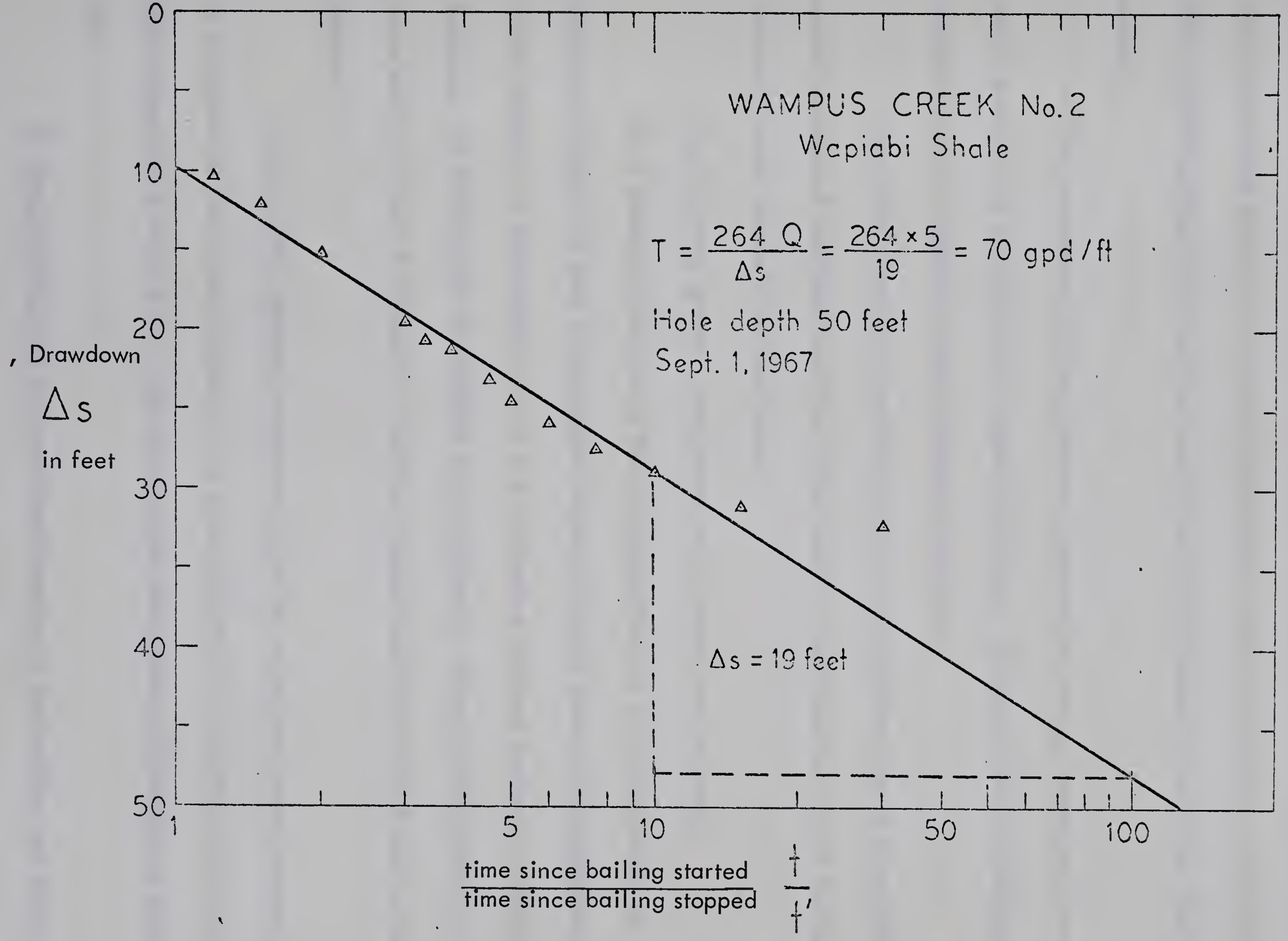
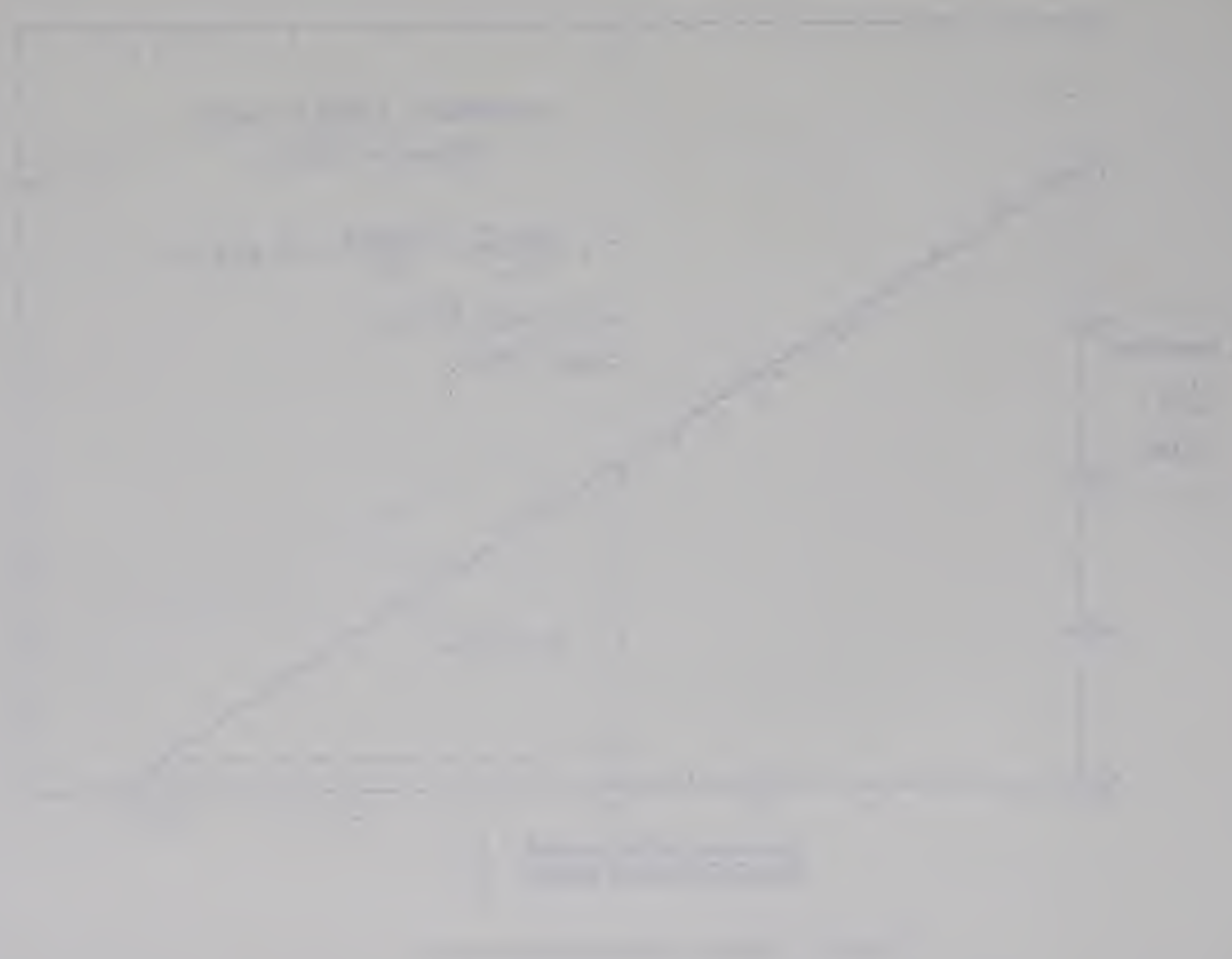


Figure 22. Bail test – Wampus Creek No. 2



SUMMARY AND CONCLUSIONS

Rocks of the Upper Cretaceous Alberta Group and Brazeau Formation are represented in Tri-Creek basin. These sandstones and shales have been subjected to folding and thrust faulting. The surficial materials in the basin include: two glacial tills, glaciolacustrine silts, local ice contact and deltaic deposits, and minor glacial outwash.

The groundwater discharge features observed are springs, seepages, hummocky ground, and a broad zone of vegetal discharge. Springs of the rock debris and soaphole types are related to local geological conditions.

The effect of geologic nonhomogeneity on groundwater flow is to provide an upward component to groundwater flow which results in an intensification of discharge features in areas underlain by fault zones.

The following specific conclusions can be drawn from the study:

a) A geometric analysis of the drainage pattern of Tri-Creek basin was carried out despite the lack of comparison values for similar areas. Two significant values emerged. A bifurcation ratio of 5.6, indicative of strong geologic control of drainage, was obtained for the Wampus Creek sub-basin. Wampus Creek flows in a strike valley for part of its length. The other streams do not and had bifurcation ratios less than 5.

Melton (1958) obtained a value of 0.694 for the ratio of stream frequency to the square of the drainage density. The values obtained for this ratio in Tri-Creek basin range from 0.44 to 0.61. This may indicate derangement of drainage by glaciation.

b) Deep gullying and the associated slumping in the northern one third of

the basin are a result of erosion of non-plastic glaciolacustrine silts. The slumping evident in Plate 5 indicates in a rather cursory manner the profound part played by groundwater in the stability of slopes. It is suggested that this feature of groundwater, which is of considerable importance in Civil Engineering, receive more attention from Hydrogeologists in future work.

c) Areas of springs, seepages, hummocky ground and meadow vegetation denote groundwater discharge conditions.

d) Movement of groundwater towards specific discharge features in Wampus Creek sub-basin is controlled by the bedding planes and joints of the Brazeau Formation.

e) Upward flowing groundwater causes effective stresses to equal zero in non-plastic material in the local till. This results in quicked ground, and springs of the soaphole type.

f) The formation of the rather large feature termed a seepage pit (Plate 16) is due almost entirely to groundwater flow. Hence the importance of groundwater as a geomorphic agent.

g) Springs of the rock debris type occur at a break in topographic slope where the surficial cover is thin. Seepage along bedding planes and joints may be a means of water egress.

h) Plant associations of lodgepole pine, broom grass and bearberry are indicative of groundwater recharge areas. A spruce-fir-haircap and sphagnum moss association indicates groundwater discharge conditions. These associations are readily discernible on air photographs.

i) The presence of meadow vegetation along a fault trace is indicative of

groundwater discharge from the fault zone.

The general conclusions arising from this study are:

a) Hydrogeological knowledge and procedures applied to the Plains region of Alberta (Clissold, 1967) are also valid in the Foothills environment.

b) The importance of intensive study of airphotos of an appropriate scale supported by field observations cannot be over-emphasized.

RECOMMENDATIONS

It is recommended that the future work in Tri-Creek basin be directed toward determination of the following hydrogeological parameters:

a) well and aquifer yields from which types, magnitudes, and three-dimensional distribution of permeabilities can be calculated;

b) geochemical nature of the waters and geologic formations;

c) configuration of the water table;

d) quantities of natural recharge and discharge.

The definition of these parameters can be accomplished by:

a) drilling of wells to facilitate pumping tests, bail tests, and core analysis;

b) further sampling and chemical analysis of naturally discharging groundwater, and waters encountered during drilling operations;

c) hand augering and drilling of water table wells;

d) procurement of meteorological data and rational estimates of natural groundwater discharge and evapotranspiration.

The end result of the present study and future work will be:

a) a manual of groundwater exploration in a Foothills environment;

b) a hydrogeological map of Tri-Creek basin;

c) an annual groundwater budget.

REFERENCES

Atlas of Canada (1957): Dept. of Mines and Tech. Surveys, Geographical Branch, Ottawa.

Chebotarev, I.I. (1955): Metamorphism of natural waters in the crust of weathering; Geochemica et Cosmochimica Acta, Vol. 8, pt. 2, p. 137-170.

Clissold, R.J. (1967): Groundwater mapping near Red Deer, Alberta; unpublished M.Sc. thesis, Univ. of Alberta, 126 pages.

Davis, S.N. and DeWiest, R.J.M. (1966): Hydrogeology; John Wiley and Sons, Inc., New York, 462 pages.

Flint, R.F. (1957): Glacial and Pliestocene Geology; John Wiley and Sons, Inc., New York, 553 pages.

Freeze, R.A. and Witherspoon, P.A. (1967): Theoretical analysis of regional groundwater flow: 2. Effect of water table configuration and subsurface permeability variation; Water Resources Research, Vol. 3, p. 623-634.

Fregren, D.H. (1967): Tri-Creek watershed investigation; unpublished report to Alberta IHD subcommittee, 10 pages.

Fulton, R.J. (1967): Deglaciation studies in Kamloops region, an area of moderate relief, British Columbia; Geol. Surv. Can. Bull. 154, 36 pages.

Jensen, E. (1966): The Brazeau Formation in the Central Foothills; Edmonton Geological Society Eighth Annual Field Trip Guidebook, p. 99-104.

Kendall, P.F. (1902): A system of glacier-lakes in the Cleveland Hills; Geol. Soc. London Quart. Jour., Vol. 58, p. 471-571.

Krumbein, W.C. and Pettijohn, F.J. (1938): Manual of Sedimentary Petrology; Appleton-Century-Crofts, Inc., New York, p. 266-267, p. 470-472.

Lang, A.H. (1947): Brule and Entrance map areas, Alberta; Geol. Surv. Can. Mem. 244, 65 pages.

Lloyd, G.V. (1955): Surface geology of Mercoal area, Alberta; unpublished Cdn. Gulf Oil Co. report, 63 pages.

MacKay, B.R. (1929): Geological map of the Cadomin sheet; Geol. Surv. Can. Map 209A.

Malloch, G.S. (1911): Bighorn Coal Basin, Alberta; Can. Dept. of Mines, Geol. Surv. Br. Mem. No. 9-E, 66 pages.

Means, R.E. and Parcher, J.V. (1963): Physical Properties of Soils; Charles E. Merrill Books Inc., Columbus, Ohio.

Meinzer, O.E. (1923): Outline of groundwater hydrology; U.S. Geol. Surv. Water-Supply Paper 494, 71 pages.

Melton, M.A. (1958): Geometric properties of mature drainage systems and their representation in an E_4 phase space; Jour. of Geol., Vol. 66, No. 1, p. 35-54.

Moss, E.H. (1955): The vegetation of Alberta; The Botanical Review, Vol. 31, No. 9, p. 493-567.

Oyama, M. and Takehara, H. (1967): Revised Standard Soil Color Charts; available from Int. Assoc. of Soil Sci., Amsterdam, Netherlands.

Roed, M.A. (1968): Surficial geology of the Edson-Hinton area, Alberta; unpublished Ph.D. thesis, Univ. of Alberta, 201 pages.

Rutherford, R.L. (1924): Geology of the foothills belt between McLeod and Athabasca Rivers, Alberta; Scientific and Industrial Res. Coun. of Alberta, Report No. 19, 61 pages.

Rutledge, P.C. (1940): Neutral and effective stresses in soils; Proc. of Purdue Conference on Soil Mechanics, Purdue Univ., p. 174-190.

Stott, D.F. (1963): The Cretaceous Alberta Group and equivalent rocks, Rocky Mountain Foothills, Alberta; Geol. Surv. Can. Mem. 317, 306 pages.

Strahler, A.N. (1957): Quantitative analysis of watershed geomorphology; Trans. Am. Geoph. Union, Vol. 38, No. 6, p. 913-920.

__________ (1964): Quantitative geomorphology of drainage basins and channel networks; in Handbook of Applied Hydrology, Ven Te Chow ed., McGraw-Hill Book Co., Toronto, Canada, p. 40-73.

Todd, D.K. (1959): Groundwater Hydrology; John Wiley and Sons, Inc., New York, 336 pages.

Toth, J. (1962a): A theoretical analysis of groundwater flow in small drainage basins; Proc. of Hydrology Symp. No. 3 - Groundwater, Nat'l. Res. Council, p. 75-99.

______ (1962b): A theory of groundwater motion in small drainage basins in central Alberta, Canada; Jour. Geoph. Res., Vol. 67, No. 11, p. 4375-4387.

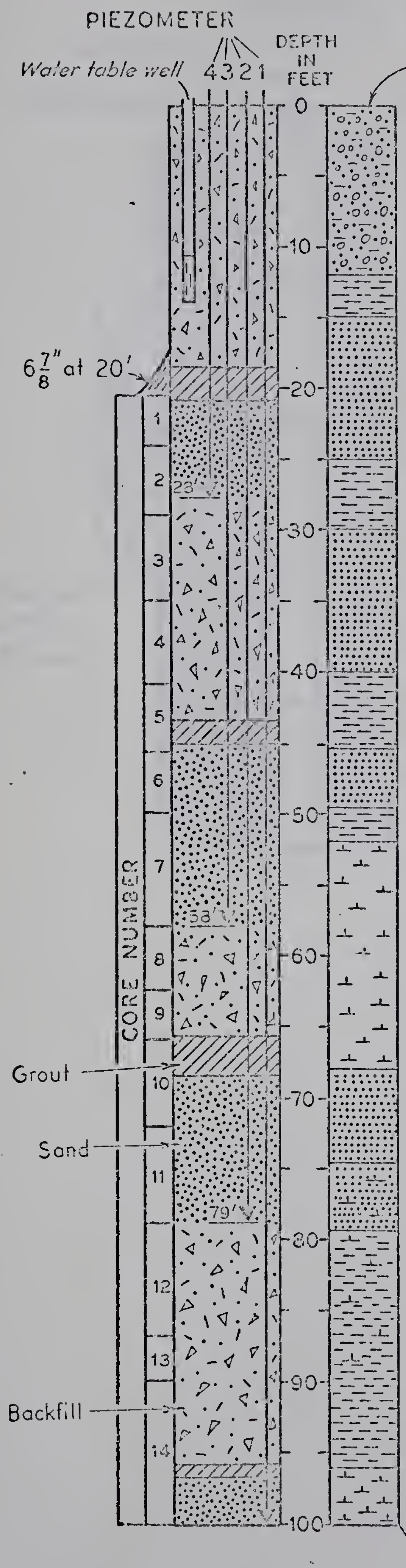
______ (1966): Mapping and interpretation of field phenomena for groundwater reconnaissance in a prairie environment, Alberta, Canada; Bull. Intl. Assoc. Sci. Hydrol., June, 1966, p. 20-68.

Vereiskii, N.G. and Vostokova, E.A. (1963): Guidebook for determining the lithological composition of surface deposits and depth of occurrence of groundwaters; Translated from Russian by Israel Prog. for Sci. Trans., Jerusalem, 1966, 246 pages.

Zernitz, E.R. (1932): Drainage patterns and their significance; Jour. Geol., Vol. 40, No. 6, p. 498-521.

APPENDIX A. STRIP LOGS AND PIEZOMETER COMPLETIONS

WAMPUS CREEK Nº1



LEGEND

- Alluvium
- Sandstone
- Shale
- Siltstone

Sand; alluvial cse grned vari-colored qtzite ss noncalc

Sand; as above but med grned

Sh; olive gry (5Y4/1) sdy plty isol rded qtz grns w/ss blwht (5B9/1) vfg noncal

Ss; blwht (5 B9/1) v fn gr #6-7 subrnded noncalc hd s and p

Ss; as above subangular

Sh; lt bl gry (5 B7/1) v calc waxy soft bent v bdly fractured

Ss; med gry (N-5) v fn grned noncalc hd s blk sh part well cem tight !!

Ss; lt gry (N-7) v fn grned subang sl calc less cem poss H_2O sd w/s sh as 25-30

Sh; brn blk (5YR 2/1) soft coaly

Sh; med gry (N-5) soft blky

Sh; ol gry (5Y4-1) hd semi fss noncalc fossil plant ?

Ss; med gry (N-5) v fn grned sl calc hard

Sh; ol gry (5Y4/1) noncalc nonfissile

Silst; lt bl gry (5 B7/1) noncalc waxy soft bent water ?

Silst; med gry (N-7) sandy hard noncalc tight

Silst; lt bl gry (5 B7/1) noncalc waxy soft bent crumbled water ?

Silst; as above w/thin interb of soft waxy bent sh (5 B7/1)

Silst; as above

Ss; med dk gry (N-4) v fn grned well cem shly hd noncalc good seal

Ss; med dk gry (N-4) shly noncalc as above probably no change

Ss; lt bl gry (5 B7/1) silty v fn gr soft waxy noncalc bent water ?

Sh; med dk gry (N-4) silty noncalc hard tight good seal

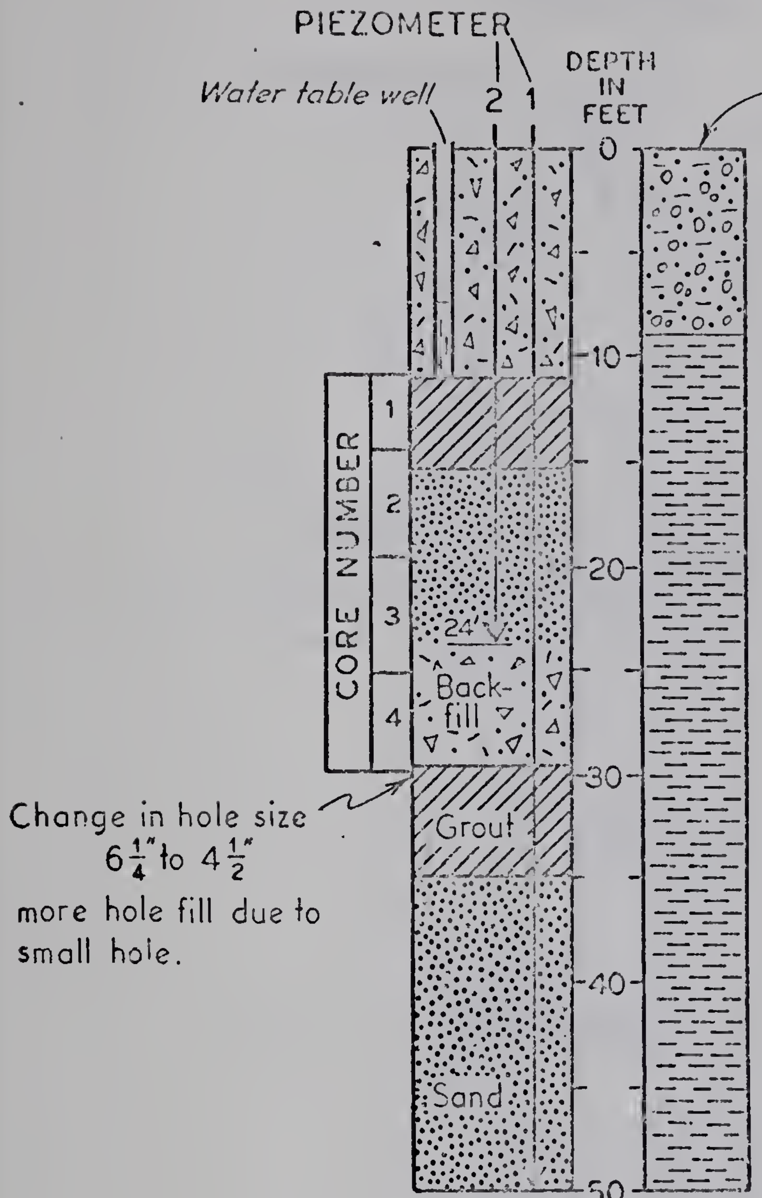
Sh; silty as above w/.5' ss med gry (N-5) v fn gr-fn gr noncalc hair line sh

Sh; dk gry (N-3) noncalc blky sweats on fract like mud cracks

Silst; lt bl gry (5 B7/1) v fn gr subang noncalc hard some sh part

Hole deepened to 102 ft (101.7)

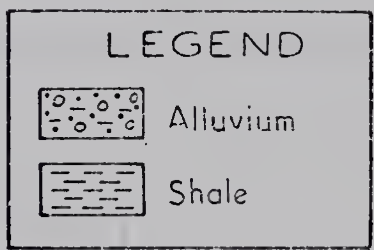
WAMPUS CREEK Nº2



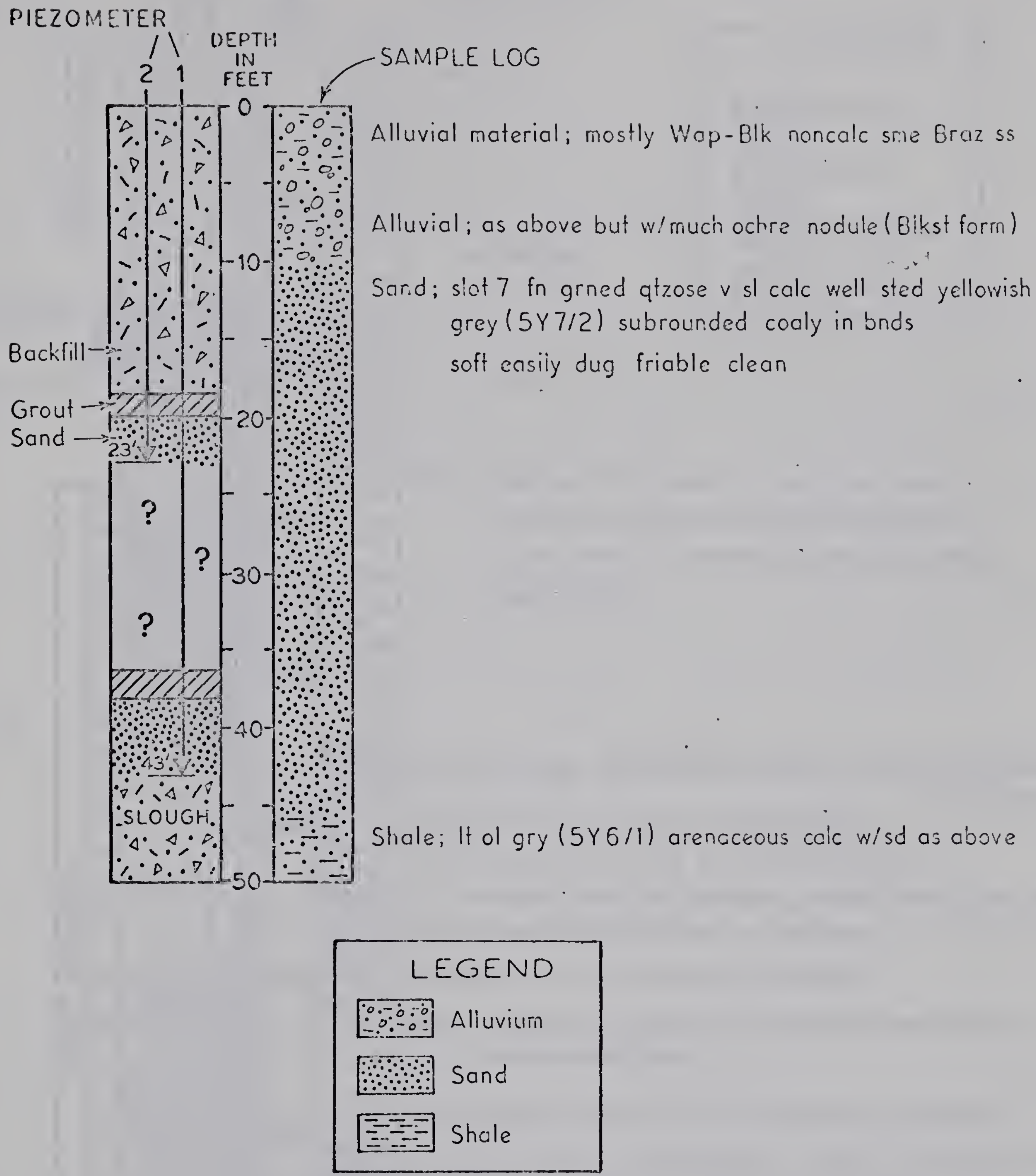
Alluvium; reworked Wapiabi Shales with some minor Brazeau Ss, local !

Shale; olive black (5Y4/1) wet dark grey (N-3) dry noncalc blky nonmic with some vert fractures; the beds are near vertical hence cored only 19 ft, great homogeneity ?

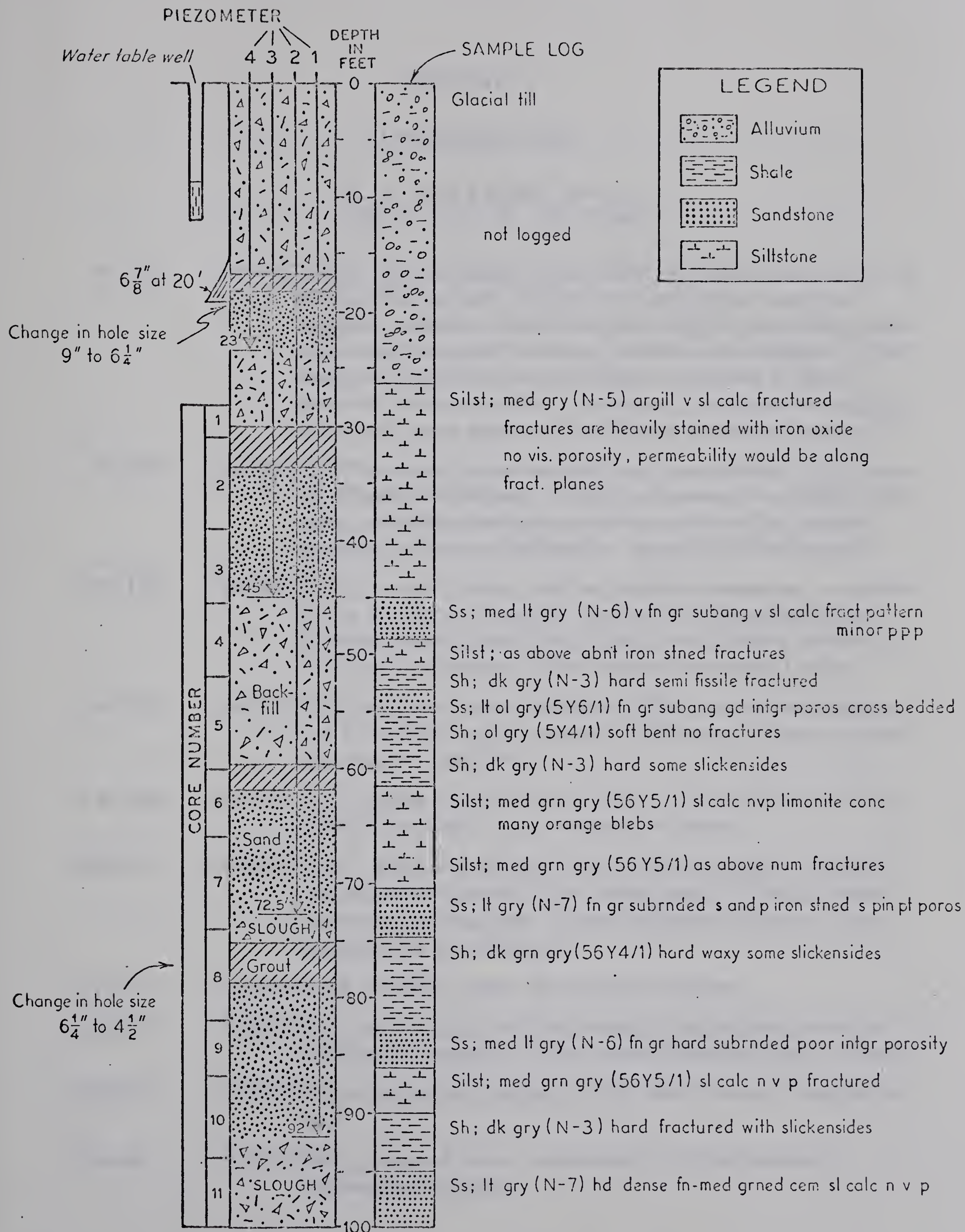
The shale is very strongly fractured. These fractures provide lateral permeability to water movement.



WAMPUS CREEK No 3



WAMPUS CREEK №4



APPENDIX B.

LITHOLOGIC LOG

B. A. et al KAYDEE 14-12
LSD 14 - 12 - 48 - 23 - W5th

40- 70	SANDSTONE, salt and pepper, fine medium to medium sub-angular to sub-rounded grained, siliceous and kaolinitic cementing material, kaolinitic material appears slightly weathered resulting in light brownish to orange coloration of sandstone, minor amounts of light grey salt and pepper sandstone as above, traces of mica noticeable in sandstone, sandstones are slightly calcareous, grey sandstone has highest calcareous content.
70-100	SANDSTONE as above, minor amounts very fine grained, light brownish to orange micaceous, slightly calcareous, few pieces siltstone, gradation from grey to brown and from fine grained sandstone tosiltstone noticeable - especially 80-90 sample.
100-140	SANDSTONE, orangey brown, salt and pepper appearance, composed of fine to coarse, unsorted, angular to sub-rounded grains, siliceous cement, kaolinitic in part, very slightly calcareous, few pieces calcareous, minor amounts micaceous biotite.
140-190	SANDSTONE as above, minor sandstone, light grey salt and pepper, fine to medium angular grained, calcareous, siliceous cementing material, kaolinitic.
190-200	SILTSTONE, medium greyish brown to brown, micromicaceous, fairly tightly compacted, minor sandstone as above.
200-10	SANDSTONE, greys and orangey brown, salt and pepper, unsorted, fine to medium grained - few large grains, siliceous cement, micaceous and kaolinitic in part, slightly calcareous - grey sandstone fairly calcareous.
210-20	SANDSTONE as above, minor amounts grey siltstone.
220-30	SILTSTONE, medium grey, micromicaceous to micaceous, traces of carbonaceous material, minor amounts medium brown siltstone
230-40	SILTSTONE, as above but grading to silty shale, trace of conglomerate.
240-60	SILTSTONES, grey and brown, micaceous to micromicaceous, carbonaceous in part.

260-70	SHALE, medium grey, micromicaceous, minor amounts silty and micaceous in part.
270-90	SANDSTONE, salt and pepper, light to medium grey, fine to fine medium, sub-angular to sub-rounded grained, very slightly calcareous, generally micaceous, traces of carbonaceous material, minor shale as above
290-320	SANDSTONE, very fine grained to SILTSTONE, light to medium grey, micaceous to micromicaceous, gradation from sandstone to siltstone noticeable in a few pieces, minor amounts grey brown to brown.
320-50	SILTSTONE, becoming shaley, light grey to brown, micromicaceous, minor amounts containing carbonaceous material, minor amounts SANDSTONE, salt and pepper, fine to medium angular grained, slightly calcareous, micaceous in part.
350-60	SHALE, light to medium grey to brown, faintly micromicaceous, slightly carbonaceous, minor amounts silty.
360-70	SHALE as above, interbedding with thin lenses of salt and pepper, fine medium grained sandstone evident.
370-90	SHALE, medium grey brown, blocky, silty in part, carbonaceous, micromicaceous.
390-400	SILTY, grey and brown carbonaceous shales interbedded with minor amounts of grey to brown, salt and pepper, medium grained sandstone.
400-10	SILTSTONE, light grey, coarse, micromicaceous to micaceous, minor amounts shaley and carbonaceous, very slightly calcareous.
410-30	SANDSTONE, light grey, very fine to fine grained, micaceous, fairly tightly compacted, minor amounts containing carbonaceous material.
430-40	SHALE, medium grey to grey brown, faintly micromicaceous, carbonaceous, minor amounts of grey, micaceous siltstone.
440-70	SILTY SHALE to SILTSTONE, grey to grey brown, micromicaceous, minor amounts carbonaceous

470-80	SHALE, predominantly light to medium grey, minor amounts grey brown, silty, micromicaceous, carbonaceous, slightly calcareous.
480-90	SHALE as above, SANDSTONE, very light grey, fine to very fine grained, micaceous, slightly calcareous.
490-520	SILTSTONE, light grey, micaceous, minor amounts carbonaceous, minor SHALE, medium to light grey, carbonaceous, silty, micromicaceous, SILTSTONE and SHALE, slightly calcareous.
520-30	SHALE, medium grey brown, faintly micromicaceous, blocky to fissile, carbonaceous, minor amounts grey siltstone and fine grained sandstone.
530-40	SHALE, medium grey, slightly silty, carbonaceous, faintly micromicaceous, predominantly blocky. SANDSTONE, light grey, fine grained, micaceous, slightly calcareous, carbonaceous in part, few pieces showing sandstone and shale contacts.
540-50	SANDSTONE, medium brown, very fine grained to silty, micaceous to micromicaceous, very slightly calcareous (burnt samples).
550-70	SANDSTONE, light to medium grey, very fine grained to silty, micaceous to micromicaceous, slightly calcareous, minor amounts of medium brown, silty, carbonaceous shale.
570-620	SANDSTONE, salt and pepper, light grey, fine medium sub-angular to sub-rounded grained, micaceous, carbonaceous in part, calcareous, kaolinitic in part.
620-30	SANDSTONE, light grey, very fine grained to silty, micaceous to micromicaceous, fairly lightly compacted, few flecks of carbonaceous material. SANDSTONE, salt and pepper, very light grey, fine medium grained, micaceous, kaolinitic, calcareous.
630-60	SANDSTONE, fine grained as above.
660-70	SHALE, medium grey, micromicaceous, blocky, minor amounts silty, odd piece containing carbonaceous material.
670-80	SHALE, medium grey to brown, micromicaceous, blocky, silty and carbonaceous in part.
680-90	SHALE, medium grey, blocky, micromicaceous, minor amounts silty.

690-710	SANDSTONE, light grey, fine grained, micaceous, slightly calcareous, few carbonaceous flecks, tightly compacted, minor amounts kaolinitic and coarser grained.
710-20	SANDSTONE, light grey, predominantly fine grained, micromicaceous to micaceous, slightly calcareous, kaolinitic in part. SANDSTONE, minor amounts, salt and pepper, very light grey, fine medium grained, micaceous, kaolinite, calcareous. SILTSTONE to SILTY SHALE, minor amounts, medium grey brown, carbonaceous in part.
720-60	SANDSTONE, salt and pepper, light grey, fine medium sub-angular to sub-rounded grained, micaceous, kaolinitic, slightly calcareous, fairly friable. SHALE, medium grey to grey brown, micromicaceous, blocky, silty, minor amounts containing carbonaceous material.
760-80	AS ABOVE but predominantly sandstone.
780-800	SHALE, medium grey, micromicaceous, blocky, minor amounts silty, few pieces containing carbonaceous material, minor salt and pepper sandstone as above, minor very fine grained to silty, light grey sandstone.

APPENDIX B.

LITHOLOGIC LOG

B. A. et al KAYDEE 5 - 7
LSD 5 - 7 - 48 - 22 - W5th

60 SANDSTONE, salt and pepper, light to medium brown to orange-brown, fine to medium subangular to subrounded grained, minor amounts of coarse grained inclusions, calcareous, kaolinitic, micaceous in part (biotite), fairly tightly compacted with calcareous and siliceous cement.

70 SANDSTONE as above, friable in part, traces of very poor intergranular porosity, no permeability.

80 SILTSTONE, very fine to silty shale, light grey, micromicaceous, fairly soft and friable, slightly calcareous, odd piece with thin carbonaceous parting.

90 SILTSTONE as above, minor amounts of grey to brown, carbonaceous shale, silty in part.

100 SILTSTONE, orange-brown, micromicaceous, slightly calcareous, odd carbonaceous inclusion. Sandstone as above.

110 SILTSTONE, light grey, micromicaceous, slightly calcareous, odd carbonaceous inclusions, grades to orange-brown siltstone (probably where weathered), few light to medium grey shale partings, odd pieces slightly waxy.

120 SANDSTONE, orange-brown, salt and pepper, fine to coarse subangular to subrounded grained, siliceous cement, generally kaolinitic, calcareous, odd piece containing biotite, traces of very poor intergranular porosity.

130-50 SANDSTONE as above, minor amounts of grey and orange-brown siltstone.

160 SANDSTONE, orange-borwn, predominantly fine to medium grained, subangular to subrounded, calcareous, very friable, sample consists mainly of loose grains. (Lost Circulation @ 150')

170 SANDSTONE as above, with light to medium grey, salt and pepper, fine to medium grained, subangular to subrounded, kaolinitic, calcareous, traces of biotite.

180-90 SANDSTONE as above, orange-brown, tightly compacted with siliceous cement, calcareous.

200 SILTSTONE and SILTY SHALE, light grey, micromicaceous, few carbonaceous partings and inclusions, trace shale slightly waxy.

210-20 SANDSTONE, light grey, very fine grained to siltstone, micromicaceous, micaceous (biotite) in part, minor amounts of light grey, micromicaceous shale. Sample consists predominantly of orange-brown. Sandstone - probably cavings.

230 SHALE, light grey to grey brown, carbonaceous, silty in part, blocky to fissile, faintly micromicaceous. Traces light green-grey, bentonite micaceous.

240 SHALE as above, becoming more silty, interbedded with light grey sandstone, carbonaceous in part, micromicaceous, slightly caclcareous.

250 SANDSTONE, salt and pepper, light grey, fine subangular to subrounded grained, slightly calcareous, fairly tightly compacted.

260 SANDSTONE as above, grading to micromicaceous siltstones and silty shales, carbonaceous in part, minor brown carbonaceous shale trace coal.

270 SILTSTONE, light grey, micromicaceous, calcareous, interbedded with minor amounts of light to medium grey to brown, carbonaceous shale.

280 SHALE, light grey to medium grey-brown, micromicaceous, grey shale is silty with minor carbonaceous material, grey-brown shale is carbonaceous with minor silt content. Grading from siltstone to silty shale is evident. Silty shale is slightly calcareous.

290 SILTSTONE to SILTY SHALE, predominantly light grey, micromicaceous, slightly calcareous, odd carbonaceous inclusion.

300 Sample Missing

305 SHALE as above, light to medium brown, carbonaceous, odd very thin coal stringers, fairly soft.

310 SHALE, light to medium grey to brown, faintly micromicaceous, fairly soft, carbonaceous with odd thin coal stringers, generally blocky fissile in part.

315 SHALE as above.

320 SANDSTONE, light grey, very fine grained to siltstone, micromicaceous,

very slightly calcareous, odd piece with carbonaceous inclusions, fairly tightly compacted.

325 SANDSTONE as above, with increase of calcareous content.

330 SANDSTONE as above, minor amounts of brown carbonaceous shale, minor amounts of very light grey blocky bentonitic shale.

335 SHALE as above, minor amounts of sandstones and siltstones.

340 SANDSTONE, light grey, salt and pepper, fine to very fine grained, micromicaceous, slightly calcareous, tightly compacted.

345 SHALE, slightly bentonitic, very light grey, clovky but will crush to a powder quite easily (possibly a mudstone).

350 SHALE as above.

355 SANDSTONE, light grey, salt and pepper, fine to very fine grained, slightly calcareous, mincromicaceous in part, minor amounts of kaolinite, odd carbonaceous parting.

360 SANDSTONE as above, grading to siltstone, fairly compacted.

370 SHALE and SILTSTONE, light to medium grey, micromicaceous and silty, carbonaceous in part, slightly calcareous.

380 SANDSTONE, light grey, salt and pepper, unsorted fine to coarse subangular to subrounded grains, kaolinitic, slightly calcareous, fairly friable.

385 SHALES and MUDSTONES, very light grey to light grey, generally blocky, traces of medium brown siderite.

390 SHALES, light to medium grey-brown, carbonaceous, slightly silty in part and sandstone, light grey, very fine grained to siltstone, micromicaceous, carbonaceous in part, calcareous to slightly calcareous.

395 SANDSTONE, light grey, very fine grained, micromicaceous, carbonaceous in part, slightly calcareous, minor amounts of siltstone and brown carbonaceous shale.

400 SANDSTONE, light grey, salt and pepper, very fine grained, micromicaceous, fairly tightly compacted, traces of carbonaceous material.

405 SANDSTONE as above, grading to siltstone, with shale, light to medium grey, faintly micromicaceous, carbonaceous, blocky, silty in part.

410 SHALE, medium grey shale as above.

420 SILTSTONE, light grey, micromicaceous, fairly tightly compacted.

430 SILTSTONE as above with shale, medium grey-brown, carbonaceous, waxy in part, minor amounts interbedded with siltstone.

440 SANDSTONE, light grey, fine to very fine grained, micromicaceous, slightly calcareous to calcareous, tightly compacted, predominantly calcareous cement.

450 SANDSTONE, light grey, very fine grained to siltstone in part, micromicaceous, very slightly calcareous, odd carbonaceous parting, fairly tightly compacted.

455 SANDSTONE as above.

460 SHALE, light grey to grey-brown in part, micromicaceous, silty, very slightly calcareous, blocky, minor amounts of siltstone.

470 SHALE as above with carbonaceous inclusions.

480 SILTSTONE, light grey, micromicaceous to micaceous in part, very slightly calcareous.

490-500 SANDSTONE, light grey, fine grained to very fine grained, micromicaceous, odd piece micaceous (biotite), non calcareous to very slightly calcareous.

510 SANDSTONE, light grey, salt and pepper, predominantly medium subangular to subrounded grained, kaolinitic, fairly friable, slightly calcareous to calcareous.

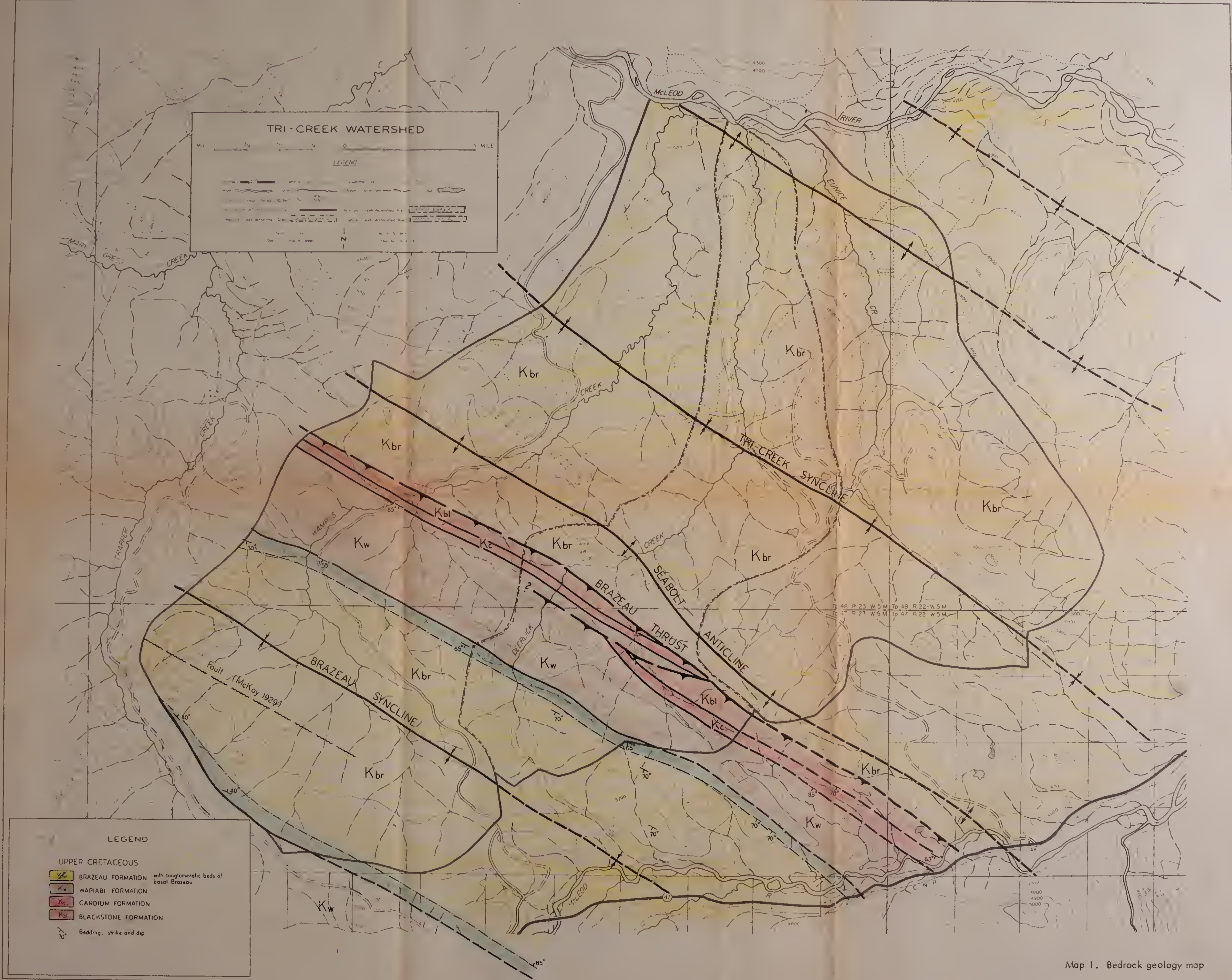
520 SANDSTONE as above, increase of calcareous content.

530 SANDSTONE as above, grading to very fine grained sandstone and siltstone with shale, light grey to brown, silty in part, micromicaceous, carbonaceous partings and inclusions.

540 SHALE, light to medium grey, micromicaceous, silty in part, few thin coal stringers, minor amounts medium grey siltstones, odd carbonaceous inclusions.

550	SHALE as above.
560	SHALE, light grey, micromicaceous, generally blocky, few silty shale to siltstone interbeds, traces of carbonaceous material.
570	SHALE, light grey to grey-green, faintly micromicaceous, slightly waxy in part, traces of whitish bentonite.
580-600	SHALE as above, few carbonaceous inclusions, traces of bentonite and coal, shiney and brittle.
610	SHALE, light grey, grey-green and slightly waxy in part, faintly micromicaceous, minor amounts silty, minor amounts soft, fissile, carbonaceous, brown shale, minor amounts whitish bentonite, trace coal.
620	SHALE as above, becoming sandy, sandstone, light grey, salt and pepper, fine to medium grained.
630	SANDSTONE, salt and pepper, light grey, fine medium subangular grained, kaolinte, slightly calcareous to calcareous, traces of mica, fairly tightly compacted.
640-710	SANDSTONE as above, interbedded in part with light grey siltstone and shale, carbonaceous in part.
720	SANDSTONE, light grey, very fine grained grading to siltstone, micromicaceous, odd carbonaceous inclusions.
730-40	SILTSTONE, light grey, micromicaceous, traces of carbonaceous material, tightly compacted.
750-60	SILTSTONE as above, minor shale, medium grey, silty in part, odd carbonaceous inclusions.
770-80	SANDSTONE to SITLSTONE, light grey, very fine grained, micromicaceous, tightly compacted, traces of carbonaceous material.
790	SHALE, light to medium grey, minor amounts brownish, generally silty and carbonaceous.
800-10	SHALE, medium grey, faintly micromicaceous, generally blocky, minor amounts of carbonaceous inclusions, odd piece slightly silty.
820	SANDSTONE, light grey, salt and pepper, medium subangular grained, kaolinite, calcareous, minor amounts of medium grey silty shale grading to siltstone, few carbonaceous partings.

830 SANDSTONE as above, coarse grained with shale, medium grey to grey-brown in part, coarse quartz grain inclusions.



Map 1. Bedrock geology map

Map . Isopach map of surficial deposits

Map 3. Surficial geology map

Map 5. Conductivity survey map